ASSESSING THE ENVIRONMENTAL EFFECTS OF URBAN TRANSIT SYSTEMS

A Manual for the Management of Stormwater Runoff at Transit Maintenance and Storage Facilities

National Urban Transit Institute

at the University of South Florida's Center for Urban Transportation Research

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At-Grade Busway Study

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16. Abstract

This research investigates the issues related to the implementation and operations of the South Dade Busway, the first at-grade busway in the United States. Busway applications in North America and through the world are also analyzed and presented through an extensive literature review. A case study about the South Dade busway is also presented in this report. Traffic data collection before and after the operation of the South Dade Busway were performed and analyzed to study the effect of the at-grade busway on traffic on adjacent streets. System characteristics of at-grade busway are compared with comparable systems. The at-grade South Dade Busway is proven to be an attractive means of transportation. The South Dade Busway ridership increased by 39% in the first month, and the combined busway and Metrorail ridership increased by 17% in the same period. Accidents due to the operation of the South Dade busway were also analyzed and new traffic control devices are proposed to ensure safer operations of the busway. The main advantages of at-grade busways include that they may be implemented quickly and incrementally and thus are responsive to growing road congestion. Important aspects of at-grade busway design and operations are safety, convenience, signal preemption for transit vehicles, and proper traffic control device design and operations.

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1. INTRODUCTION

Surface public transportation is easily affected by increased traffic congestion in urban areas. Thus, it is becoming more challenging to provide the public with a high level of service, including speed, comfort, and reliability. Consequently, it is necessary to improve and promote other forms of urban transportation to meet the demands of the environment and mobility requirements in metropolitan areas. Throughout the world, a wide variety of bus priority projects and proposals involved busways as a solution to improve and promote public transportation. The latest bus lane was recently inaugurated in Beijing, China to alleviate traffic congestion in the Chinese capital. The purpose of the bus priority facilities is to increase the passenger capacity of the roadway network rather than the vehicular capacity. A bus can carry 20 times as many passengers as a car and contributes only three times as much to congestion (NATO 1976).

Today, buses are the most widely used transit technology. They are operated in nearly all cities with transit service, in a majority of them as the only transit mode. The most important characteristics of buses as a transit mode result from three basic features: the ability to operate on virtually all streets, very low investment cost, and limited-capacity transit units, which are ideal for light to moderate travel transit routes.

Bus-only facilities provide improved local transit service reliability and increased travel speed on local streets or on separate rights-of-way. The prevalent types of bus-only facilities are bus lane(s) along the street, bus streets on an existing right-of-way, and busways on a separate right-of-way.

The concept of bus lanes is well known. A bus lane is the part of the road space reserved for buses and marked by pavement markings and signs. A bus lane gives buses priority over other vehicles, leading to fewer delays, especially on the approach to junctions (Gardener 1992). Busways are two-way-roadways or lanes developed on a separate right-of-way and designated for the exclusive use by buses (Fuhs 1993). Busways can also be defined as controlled access facilities dedicated for bus service that are separated from general traffic, often with grade-separated right-of-way. A variety of busway layouts are possible, including lateral busways in the near side lane, and median busways which occupy the central reserved lane(s) of the roadway. Busways can also be located in a separate roadway within a freeway or arterial road right-of-way, either in the median or along one side of the road as shown in **Figure 1.1**. Excellent busway facilities have been built in several cities around the world, including Miami, Ottawa, Pittsburgh, Runcorn, Redditch, Evry, Curitiba, Los Angeles, Northern Virginia, and Houston.

Busways have several positive characteristics. They do not require introduction of new technology with separate installations (Vuchic 1983). They can be built for any section of existing bus lines where suitable physical conditions and service warrants exist, and utilized incrementally, similar to the improvements of individual sections of light rail transit (LRT) rights-of-way. They can be used by many bus routes serving a large area and speed up their operations along heavily congested corridors. Busways combine the flexibility of a bus, which can go anywhere there is an adequately paved street or highway, with the freedom from traffic intervention that is enjoyed by other modes of rapid transit (Martinelli 1996). Because buses can operate on most city streets mixed with general traffic serving residential neighborhoods, they can join the exclusive busway facility and in most cases can provide a one seat connection, or in some cases no more than two transfers. The implementation period for the busways are relatively shorter than other transit modes with a relatively low cost and less disturbance to other traffic during construction.

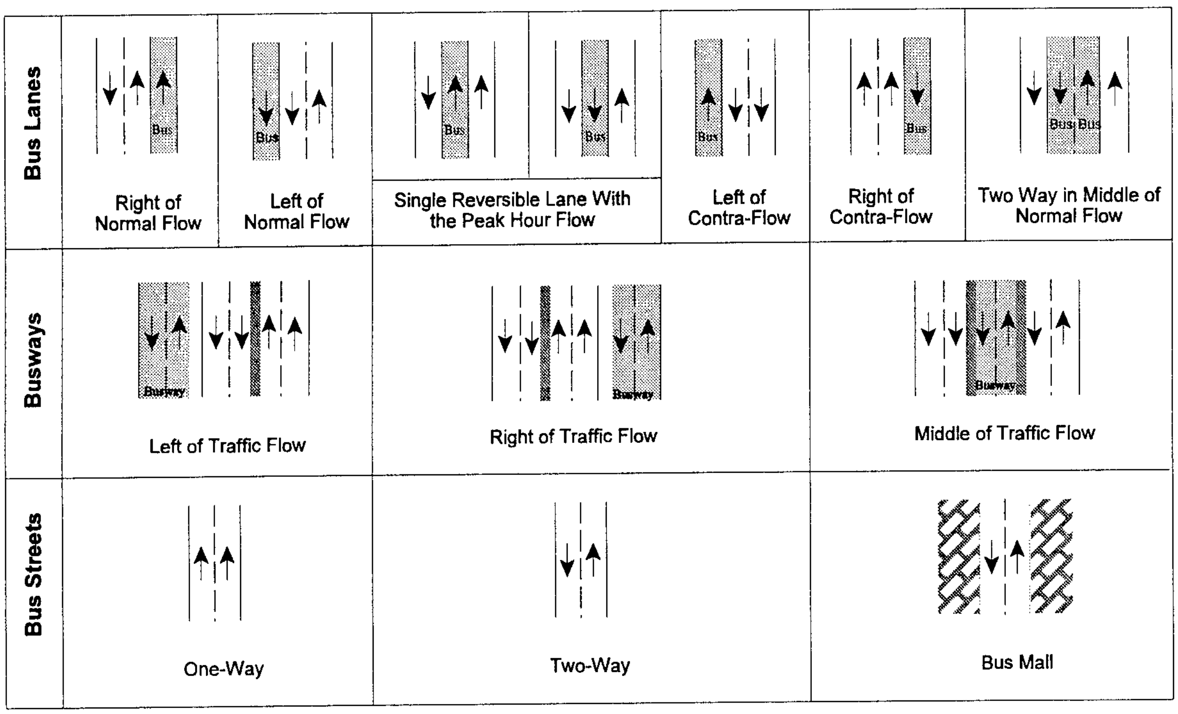


Figure 1.1 - Different Types of Bus Priority Treatments

Exclusive busways on their own rights-of-way with complete control of access provide the highest level of service. These facilities can penetrate and effectively serve tributary areas. Intermediate stations and access ramps may be provided as necessary. Design standards of busways can be tailored to specific operations, and it is not necessary to limit vehicle size, operating speed, or hours of operation.

Although busways assure separation of buses from other vehicles, they are costly and slow to implement relative to regular bus services. On the other hand, their costs are less than those for light rail and heavy rail systems. Moreover, the environmental impact and the required right-of-way for busways are much less than those for highways. Little-used or abandoned rail systems may also provide inexpensive right-of-way and ready-made sub-grade for busways. Summarized characteristics of busways operated in North America are shown in **Table 1.1**, which are discussed in more detail in a later section of this report.

Table 1.1 - Summary of Busways and HOV Facilities in the U.S.

HOV Facility	Number of Lanes	Length (miles)	Operation Period (Hours)	Requirements
BUSWAY				
Miami, FL				
- South Dade Busway	1 ED	8.2	24	Buses Only
Ottawa, Ontario, Canada				
- Southeast Transitway	1 ED	6.0	24	Buses Only
- West Transitway	1 ED	5.1	24	Buses Only
- Southwest Transitway	1 ED	2.2	24	Buses Only
- East Transitway	1 ED	4.0	24	Buses Only
- Central Transitway	1 ED	2.1	24	Buses Only
Pittsburgh, PA				
- East Patway	1 ED	6.2	24	Buses Only
- West Patway	1 ED	4.1	24	Buses Only
- Airport Busway[a]	1 ED	7.0	N/A	Buses Only
BARRIER-SEPARATED: TWO-WAY HOV				
Los Angeles, CA				
- El Monte(San Bernardino Fwy)	1 ED	4.0	24	3+ HOV
BARRIER SEPARATED : REVERSIBLE FLOW HOV				
Northern Virginia				
- I-395 (Shirley Hwy)	2 Rev	15	24	3+ HOV
Houston, TX				
- I-10 (Katy Fwy)	1 Rev	13	5 AM- noon 2 - 9 PM	3+ HOV 2+ other times
- I-45 (Gulf Fwy)	1 Rev	12.1	5 AM- noon 2 - 9 PM	2+ HOV
- US 290 (Northwest Fwy)	1 Rev	13.5	5 AM- noon 2 - 9 PM	2+ HOV
- I-45 (North Fwy)	1 Rev	13.5	6 AM- noon 2 - 9 PM	2+ HOV
- US 59 (Southwest Fwy)	1 Rev	11.5	5 AM- noon 2 - 9 PM	2+ HOV

ED= Each Direction REV= Reversible

[a]Under Construction

Source: High Occupancy Vehicle (HOV) Lanes Marketing Manual, U.S. Department of Transportation, September 1994.

Following the introduction, **Section 2** presents successful implementations of exclusive busways and roadways in North America and other cities of the world. **Section 3** represents a brief description of some light rail transit systems in the United States that have similar operation characteristics to at-grade busways. **Section 4** presents a case study for the South Dade Busway, Miami, Florida, which is the latest busway project to be implemented in the United States. Finally, **Section 5** presents the conclusion and lessons learned from the current operating busway systems.

2. LITERATURE REVIEW

2.1 OTTAWA - CARLETON TRANSITWAY, ONTARIO, CANADA

Ottawa-Carleton is a regional municipality in the Province of Ontario. It includes eleven urban and rural municipalities including Ottawa, Canada's capital. The transitway concept first materialized in the early 1970s when the need to meet the demands of a rapidly growing population was recognized. 90% of the population of the 650,000 persons in Ottawa reside within its urban area. Federal government jobs account for 22% of all jobs in the region and half of the 28% of all jobs that are located in the downtown area (Bonsall 1989). OC Transpo, the transit operating authority in Ottawa-Carleton, has the most extensive busway in North America. The current system shown in **Figure 2.1**, consists of 19.4 miles (31.1 Km) and 24 stations. The current length of the transitway that was approved in 1978 was completed in 1996 at a cost of $420 million (Canadian).

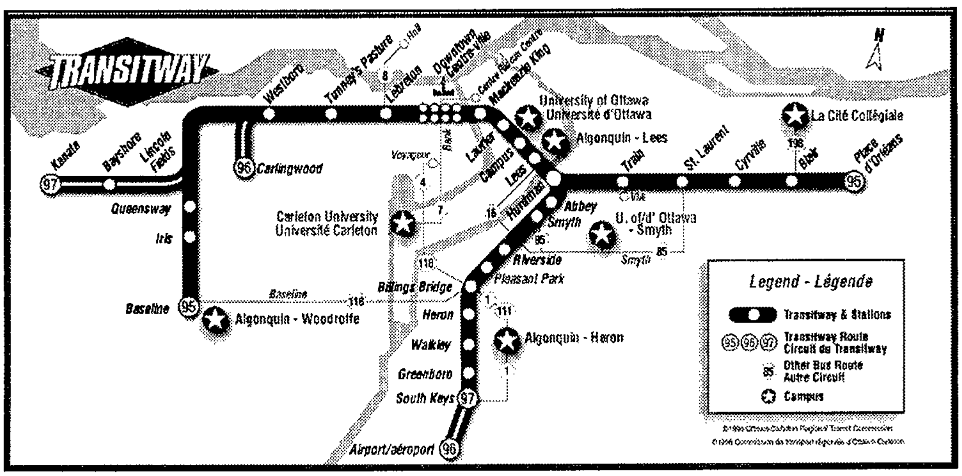


Figure 2.1 - Transitway Network in Ottawa

The busways in Ottawa are designed so that Ottawa's bus rapid system will be able to accommodate a large increase in the passenger demand in the future. The system could also be converted to a light rail or a heavy rail if the future levels of ridership make such conversion necessary.

The Transitway in Ottawa consists of four lines. *Southwest Transitway* - between Algonquin College and Carling Avenue. *West Transitway* - linking the Ottawa River Parkway near Dominion Avenue to Albert Street at Empress Avenue in downtown. *Southeast Transitway* - linking Mackenzie King Bridge downtown to Billings Bridge. *East Transitway* - between Hurdman Station and Gloucester City Center near Blair Road.

The currently operated 19.4 mile (31.1 km) busway system is fully grade-separated for most of its length. Different types of grade separation for the Ottawa Transitway system are shown in **Figures 2.2 and 2.3**. The only exceptions are the 1.4 mile (2.25 km) downtown section, which consists of concurrent flow reserved bus lanes, and the 2.3 miles (3.7 km) of parkway operation in mixed traffic. Buses operate up to their maximum speed of about 55 mph (90 km/hr), but restricted to 30 mph (50 km/hr) in station areas.

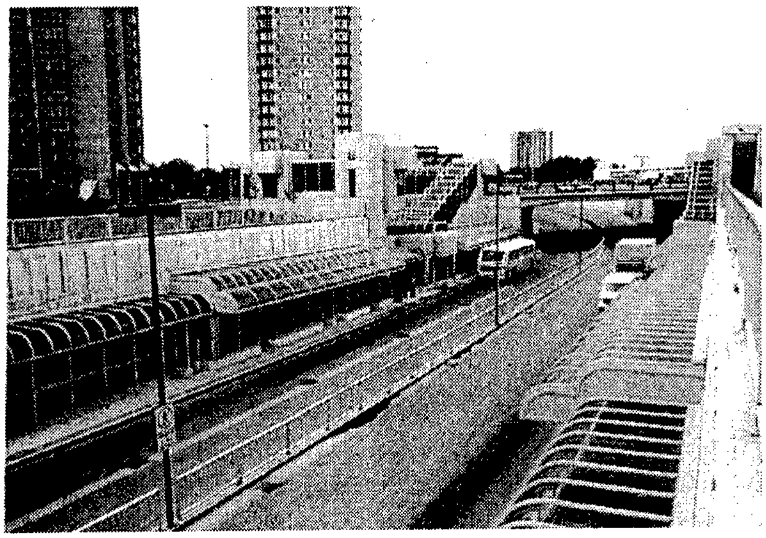


Figure 2.2 - On-line Transit Station

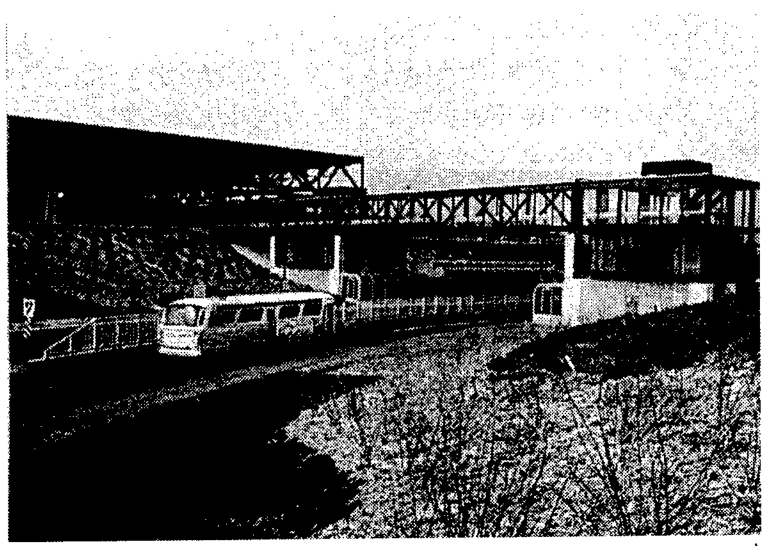


Figure 2.3 - Ottawa Transitway System

A typical cross section for the Ottawa Transitway is shown in **Figure 2.4**. The width of the transitway is 26 feet (8 m) width and 49 feet (15 m) width at stations. In the downtown area, the transitway operates on a pair of one-way streets, and bus lanes occupy the second right curb lane on four-lane one-way streets. This leaves the curb lane available for bus stopping areas, passenger platforms, general parking, and a commercial delivery area. Providing transit operations in a single curb side lane resulted in considerable delay for transit vehicles at all transit stop locations, and at all locations where general traffic entered this lane to complete right turning movements onto side streets or off street parking areas. Also, due to the many transit stops located in the central area, and the restricted width of the sidewalk at many of these locations, pedestrian and transit passengers experienced serious crowding and circulation problems. This resulted in transit loading delays and conflict between transit passengers and pedestrians. For these reasons, buses currently occupy the second right curb lane.

The transitway in the central area is shown in **Figure 2.5**. The transitway corridor in the downtown area is also reserved for general traffic, pedestrian, and cyclists. This portion of the transitway is controlled by the same traffic signal that all general traffic and pedestrians use.

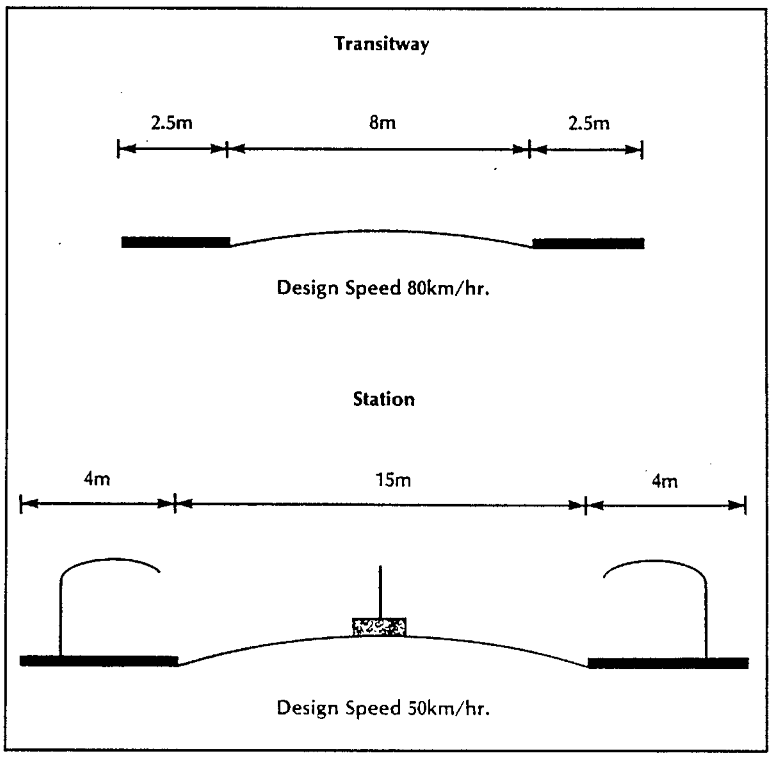


Figure 2.4 - Typical Cross-Section of Ottawa Transitway

Today, the Transitway provides an exclusive rapid link for more than 200,000 daily passengers and 10,000 passengers per peak hour per direction (OC Transpo Fact Sheet 1996). The key of the transitway system is its series of stations designed to facilitate the efficient operation of local and regional transit routes and all major urban centers. The transitway routes were also planned to serve a sizable proportion of the work trips with a maximum of one transfer and most of the remainder by no more than two transfers. OC Transpo currently provides four park-and-ride lots of a total of 1,535 spaces for busway passengers. OC Transpo also provides eight bike-and-ride locations equipped with modern racks to secure bikes. Kiss-and-ride is also available where special areas are available at most stations for vehicles to wait and pick up passengers.

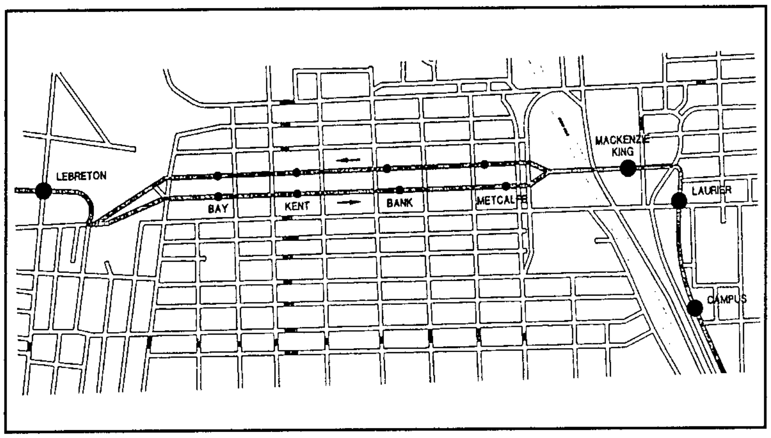


Figure 2.5 - Ottawa Transitway in the Central Area

Due to the high volume of transit vehicles that reaches up to 180 transit vehicles during the peak hour, optimization was necessary to improve and maintain the transit operation in the central area (Dillon 1993). The station and intersection capacities during the peak periods are presented in **Tables 2.1 and 2.2**, respectively. Pedestrian delays at traffic signals and cyclist service levels are heavily influenced by transit activity, where they were found to be minimized for the cycle length utilized at all signals within the central area. The utilized cycle length is 60 seconds during peak periods and 55 seconds during the off-peak periods.

Table 2.1 - Station Capacity in the Central Area (buses/hour)

Station	Westbound		Eastbound	
	AM Peak	PM Peak	AM Peak	PM Peak
Mackenzie King Station	120-170	120-170	120-170	120-170
Metcalfe Station	140-170	140-170	240	240
Bank Station	140-170	140-170	240	240
Kent Station	240	240	240	240
Bay Station	240	240	284	284

Source: Review of the Traffic Signal Operation on the Ottawa Central Area Transitway, Final Report.

Table 2.2 - Intersection Capacity in the Central Area (buses/hour)

Intersection	Westbound		Eastbound	
	AM Peak	PM Peak	AM Peak	PM Peak
Laurier	450	450	450	450
Waller	335	335	579	579
Rideau Ped. Sig	480	480	480	480
Elgin	412	290	435	413
Metcalfe	429	429	446	549
O'Connor	532	532	498	498
Bank	566	566	464	498
Kent	429	429	446	498
Lyon	378	378	446	446
Bay	500	500	635	532
Bronson	394	394	377	377
Empress	500	500	270	270

Source: Review of the Traffic Signal Operation on the Ottawa Central Area Transitway, Final Report.

The total construction cost for the Ottawa Transitway is $420 million (Canadian) (OC Transpo Fact Sheet 1996), as shown in **Table 2.3**. The average construction cost per mile is $21.8 million including the transitway, lanes, station facilities, and engineering and property acquisition. The construction cost of stations ranges from $1.8 million (Canadian) to $15 million (Canadian) as presented in **Table 2.4**.

Table 2.3 - Detailed Description of the Transitways in Ottawa

In Service	Miles (Km)	Stations	Cost[a] (Year) (Canadian)	Operation
Orleans to Blair	*4.8 (7.7)*	1	$ 20 (1994)	Freeway Bus Lane (a.m. peak)
Blair to Hurdman	4.1 (6.5)	4	$ 98 (1989)	Exclusive Transit
Hurdman to Laurier	1.7 (2.7)	3	$ 50 (1985)	Exclusive Transit
Laurier to Lebreton	1.25 (2.0)	6	$ 1 (1987)	Bus Only Lanes and Bus Stops
Lebreton to Ottawa River Parkway	3.1 (4.9)	3	$ 51 (1994)	Exclusive Transit
Ottawa River Parkway to Lincoln Fields	2.1 (3.3)	0	N/A	Joint Use on Parkway
Lincoln Fields to Baseline	2.2 (3.5)	4	$ 35 (1984)	Exclusive Transit
Hurdman to Riverside	1.3 (2.1)	3	$ 37 (1991)	Exclusive Transit
Riverside to Billings Bridge	1.1 (1.8)	2	$ 52 (1996)	Exclusive Transit
Billings to Hunt Club Rd.	2.7 (4.3)	4	$ 76 (1995)	Exclusive Transit
TRANSITWAY	**19.4 (31.1)**	**24**	**$ 420**	not including Orleans to Blair
FREEWAY BUS LANE	**8.5 (13.5)**	**0**	**N/A**	
TOTAL	**27.9 (44.6)**	**24 (6)**	**$ 420**	

[a] Cost includes: construction of transitway, lanes, stations, station facilities, and engineering and property acquisitions.

Source: OC Transpo Fact Sheet 1996.

Table 2.4 - Station Construction Costs and Completion Year

Station	Cost (10^6) (Canadian)	Year Completed	Station	Cost (10^6) (Canadian)	Year Completed
Baseline	$2.50	1983	Cyrville	$2.00	1990
Hurdman	$2.90	1983	Abbey	$2.10	1991
Lees	$4.40	1983	Riverside	$4.30	1991
Lincoln Fields	$6.00	1983	Smyth	$2.40	1991
Queensway	$4.50	1983	Greenboro	$3.00	1994
Campus	$2.10	1984	Heron	$1.80	1994
Tunney's Pasture	$4.80	1984	Orleans	$8.50*	1994
Westbor	$4.60	1984	Walkley	$2.90	1994
Train	$2.10	1986	Billings Bridge	$10.50	1996
St. Laurent	$15.00	1987	Pleasant Park	$2.10	1996
Blair	$8.00	1989	South Keys	$4.30	1996

*Includes Highway 17 pedestrian overpass.

2.2 PITTSBURGH'S BUSWAYS

The Port Authority of Allegheny County, through its Port Authority Transit Division (PAT), is the only operator in the United States that has built and operated exclusive busways (US DOT, Jan 1992).

In the 1950's, PAT replaced over 520 miles (832 km) of street railway (trolley and streetcar) lines with diesel buses, primarily as an economy measure. In 1968, an ad hoc Rapid Transit Technical Committee, created by PAT (May 1965), endorsed three rapid transit facilities as the first phase of a county-wide rapid transit system. The committee also recommended building two exclusive busway corridors south and east of the Central Business District (CBD) shown in **Figure 2.6**.

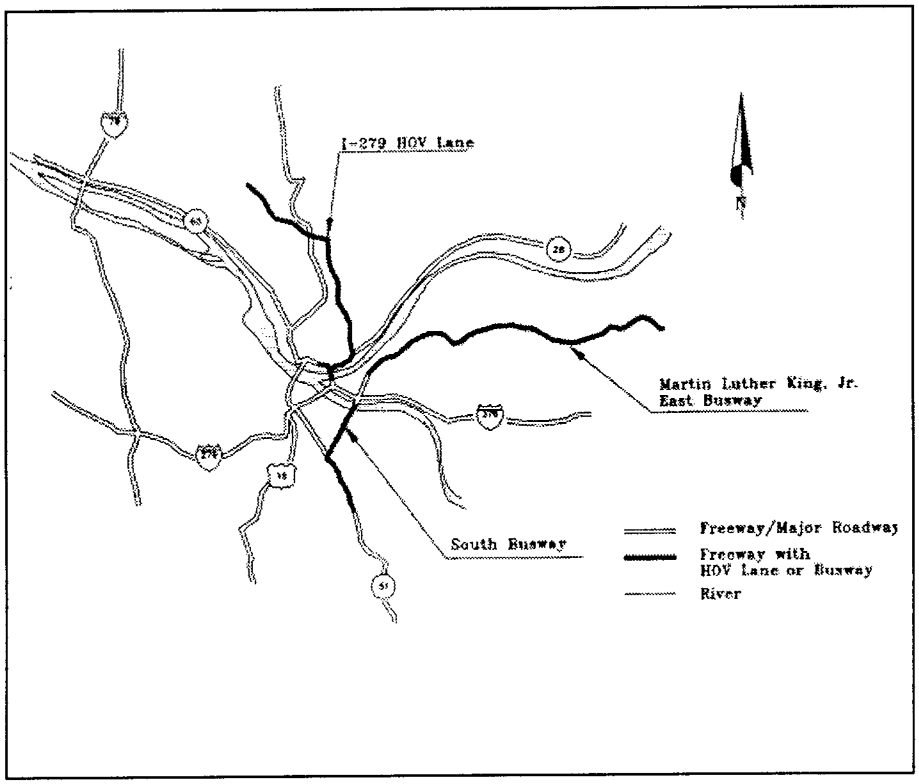


Figure 2.6 - Pittsburgh Busway System

2.2.1 South Busway

The South Busway consisting of 4 miles (6.5 km) was built in 1977 at a construction cost of $27 million to bypass severe congestion at the Liberty Tunnel which is the major roadway link between the Pittsburgh CBD and the South Hills area (US DOT, Jan 1992).

To achieve the objective of building the South Busway, PAT refurbished the adjacent 3,500 foot (1,170 m) long Mt. Washington Trolley Tunnel for use by buses, streetcars, and light rail vehicles.

In addition, PAT built a new bus-only roadway along the route 51 corridor between Glenbury Street and the Monongahela River.

The exclusive bus-only portion of the busway in the South Hills area extends for 1.7 miles (2.7 km) and consists of two 14-foot wide one-way lanes with curbs on each side. The design although not very generous, provides sufficient space to pass disabled buses. Trolleys share the remaining 2.1 miles (3.4 km) of transitway. The bus-only portion of the busway operating speed is 40 mph (65 km/hr), while the bus/trolley segment is 30 mph (50 km/hr) (US DOT, Jan 1992).

While most buses enter or leave the South Busway at the two ends of the busway, intermediate ramps are provided. The 11 stops along the South Busway are not equipped with park and ride facilities. These stops are described as platforms reachable by stairs or ramps from the local streets. Buses using the busway save an average of 6-11 minutes of trip time over pre-busway conditions. PAT estimated that the South Busway eliminated over 160 bus trips per day from congested streets in the South Hills. The implementation of the busways has influenced transit ridership as shown in **Table 2.5.** The South Busway's effect on transit ridership exceeded all expectations resulting in ridership gains of up to 16 percent for routes using the busway in its first full year of operations.

The South Busway demonstrates that a short low-cost exclusive busway in a heavily congested corridor with difficult terrain can produce significant service improvements and cost-savings (US DOT, Jan 1992).

2.2.2 East Busway

A large increase in the traffic congestion of Pittsburgh's eastern corridor with peak period back-ups of up to seven miles (11.3 km) existed at the entrance to Squirrel Hill Tunnel on the Penn Lincoln Parkway. The addition of a third tube to the tunnel and rebuilding of the parkway would take several years and traffic would be severely disrupted. Therefore, including the East Busway in the Early Action Program (EAP) were fears of gridlock in the corridor (US DOT, Jan 1992). The East Busway, also called Martin Luther King, Jr. Busway, was accepted as an interim solution with the condition of being designed in such a way so that it could be converted into LRT in the future.

The East Busway as shown in **Figure 2.6** is a 6.8-mile (11-km) grade separated exclusive two-lane, two-way roadway that connects Pittsburgh Central Business District (CBD) and the eastern suburb of Wilkinsburg. The construction of the East Busway began in August of 1978 and was completed in 1983 at a construction costs of $115 million as shown in **Table 2.6**. The construction involved replacing four existing Conrail tracks with two new tracks and a two-lane, two-way busway. The construction also called for building a wall to separate the railroad and the busway, relocating utilities, lowering the track bed in places, reconstructing auto and pedestrian bridges, building bus ramps, and providing stairs and ramps to enable passengers to reach below-grade busway stations.

The East Busway width is 34 feet (10.4 m) for most of its length. In most sections it has two 12-foot (4 m) lanes, an 8-foot (2.5 m) outbound (eastbound) right hand shoulder, and a 2-foot (0.6 m) inbound (westbound) right hand shoulder. Shoulder widths are narrower at a few points, and lanes are narrowed to 11 feet (3.4 m)each for a distance of 0.1 mile (0.16 km) west of East Liberty Station. Each station is equipped with a stopping lane in each direction allowing express buses to pass other buses picking up and off-loading passengers.

Three types of services are provided by buses using the East Busway: (US DOT, Jan 1992)

1. The busway combines the local bus service with the fixed guideway express service.
2. Flyers and express routes pick up passengers at designated park-and-ride facilities and provide fast express service to the Pittsburgh CBD.
3. Two routes provide fast, frequent, and dependable "along the line" service to inner-city users who board and disembark at busway stations or in the downtown, operating much like a rapid transit system.

The East Busway serves 16 distinct neighborhoods that include upper, middle and lower class income levels. Of the 31 PAT bus routes using the East Busway, 29 are express or flyer services and the other two are the East Busway All Stops (EBA) providing frequent service to downtown Pittsburgh and the East Busway Oakland (EBO) providing service directly to Oakland from the Wilkinsburg, Homewood, East Liberty, and Negley Avenue. The EBA and EBO are "busway routes" which stop at all busway stations. While the flyer routes serve outlying suburban communities, express routes serve communities located closer to the eastern terminus of the busway. Unlike the busway routes, most limited stop flyer and express routes only stop at 2 of the 6 East Busway stations and all bus routes using the busway, with the exception of the EBO, collect and distribute passengers in Pittsburgh's CBD.

Buses can enter or leave the East Busway facilities at any of its 6 stations. Station platforms are 120 feet (42 m) long and can accommodate 2 buses, with the exception of the East Liberty and Penn Stations which are 240 feet (84 m) long and accommodate four buses. Of the total length of the East Busway, 36% are exclusive right-of-way while the remainder 64% are right-of-way on shared city streets.

The total separation of bus traffic from other vehicular traffic, shown in **Figure 2.7**, gives the Martin Luther King, Jr. East Busway a safety advantage over any other bus transit facility in the United States (Wohlwill 1996).

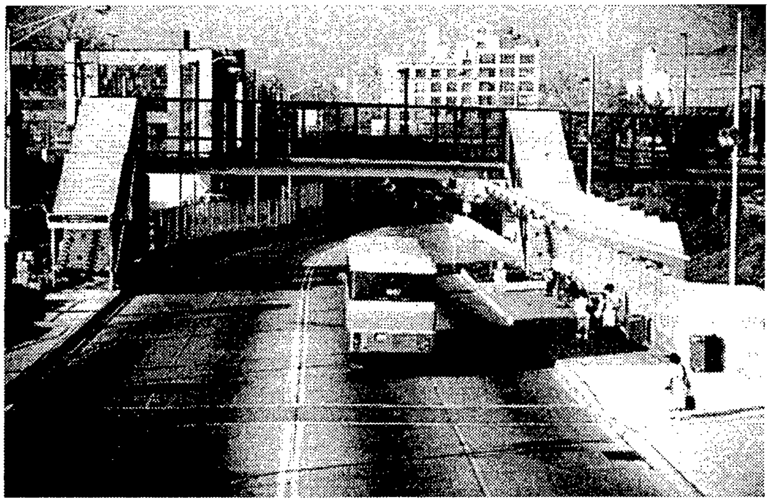


Figure 2.7 - Pittsburgh's East Busway
(Source: NCHRP Synthesis 185)

Three pedestrian overpasses were constructed at high volume station areas (shown in **Figure 2.7**). Grade separated street crossings and platform pull off lanes at stations add safety features that were incorporated in this facility. Along most of the two 12-foot-wide (4.0 m) busway lanes, 8-foot-wide (2.5 m) concrete shoulders have been constructed. This design allows the safe passing of disabled vehicles, snow removal and storage, and operational clearance. Special speed restrictions are enforced in areas where shoulders do not exist. The busway is only accessible at station areas due to the security fencing along the route. Air and noise pollution was also reduced by designing the busway with an average one percent and maximum four percent grade (Wohlwill 1996). The pull-over capabilities at each station further reduce pollution by minimizing stopping and starting of buses. PAT also allows police and emergency vehicles access to the busway. These are some of the precautions that have helped make the East Busway a safe and efficient means of travel.

2.2.3 Airport Busway

The Airport Busway is one of Allegheny County's new roadways that is under construction. The busway is anticipated to be completed in the year 2001. This will result in a two lane, seven mile (11.2 Km), bus-exclusive facility that will increase transit ridership to over 50,000 riders per day.

The capital costs for the construction of the Airport Busway is estimated at $310 million, this is shown in **Table 2.6**. The busway provides direct access to downtown Pittsburgh and the developing employment areas, which will save commuters a considerable amount of traveling time.

Table 2.5 - Ridership Statistics for the South and the East Busways in Pittsburgh

Routes	Total
Average Daily Ridership by South Busway Routes	
West Liberty	9,681
Saw Mill Run	8,336
Average Daily Ridership by East Busway Routes	
Express	10,746
Flyers	4,953
EBA	11,812
EBO	1,605

Source: PAT Ridership Analysis, March 1987.

Table 2.6 - Summary of Busway Characteristics in Pittsburgh

Characteristics	South Busway	East Busway	Airport Busway
Length (miles)	4.0	6.8	8.1
Stations	11	6	8
Access Points	5	7	6
Park-and-Ride	N/A	N/A	7
Average Weekday Ridership	16,459	24,678	53,000
Daily Bus Trips	835	848	-
Bus Routes	37	37	-
Construction Cost (million)	$27	$115	$310*
Year Opened	1977	1983	2001

Source: PAT Busways Fact Sheets, December 1995.

** Obtained from ISTEA Update*

2.3 Runcorn, United Kingdom

Runcorn, a town located 18 miles (29 km) southeast of Liverpool, is one of the first cities to have a busway with an objective-purpose built, segregated, bus-only roadway (NATO 1976). The population of the city was estimated to grow from 30,000 to 100,000 between 1973 to 1990. Thus, Runcorn city was planned around an 11-mile (17.7-km), two-lane roadway to be used mainly by buses. Residential, recreational, commercial, and industrial areas and schools were to be served by these buses.

As proposed in 1973, approximately 22 percent of the busway alignment, shown in **Figure 2.8**, shares the right-of-way with general traffic, 14 percent is an expressway on which buses operate with other traffic, and the remaining 64 percent of the busway runs in an exclusive right-of-way. To encourage the use of buses, the city located automobile parking further away from major land uses than corresponding bus service stops (this includes residential areas). Buses operate every five to seven and one half minutes during off-peak hours, and bus service stops will be located within a five minute radius walking distance. Bus journey speed on the busway averages 13-16 mph (20-25 km/h). However, in unreserved sections such as local roads, the operating speed depends on the traffic conditions. Construction cost for the busway was estimated to be $12.5 million (1973 dollars). About 90 percent of this cost is attributed to grade separation, which includes an elevated section through the city's center.

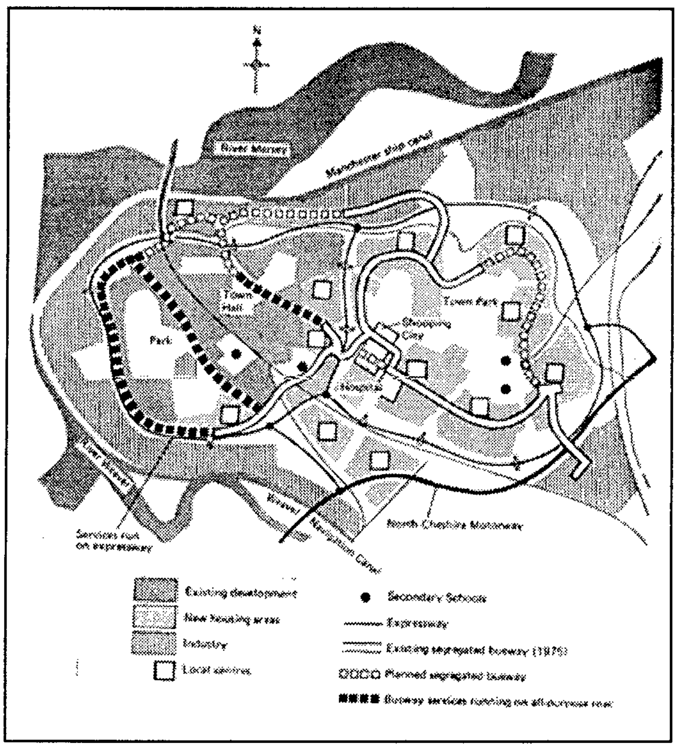


Figure 2.8 - Runcorn Busway System

According to Mr. John Austin of Austin Analytics in the United Kingdom, the Runcorn busway is presently in operation, but is not quite as well used as originally envisaged, which may be a result of bus deregulation in the United Kingdom.

2.4 Redditch, United Kingdom

Redditch City, **shown in Figure 2.9**, was constructed around a 14 mile (22.5 km) continuous roadway that includes about 6 miles (9.7 km) of exclusive and 8 miles (12.9 km) of semi-exclusive busways. The aim of designing this new town situated 14 miles (22.5 km) south of Birmingham was to provide a busway that allows a higher speed and frequency of bus operation than would normally be possible.

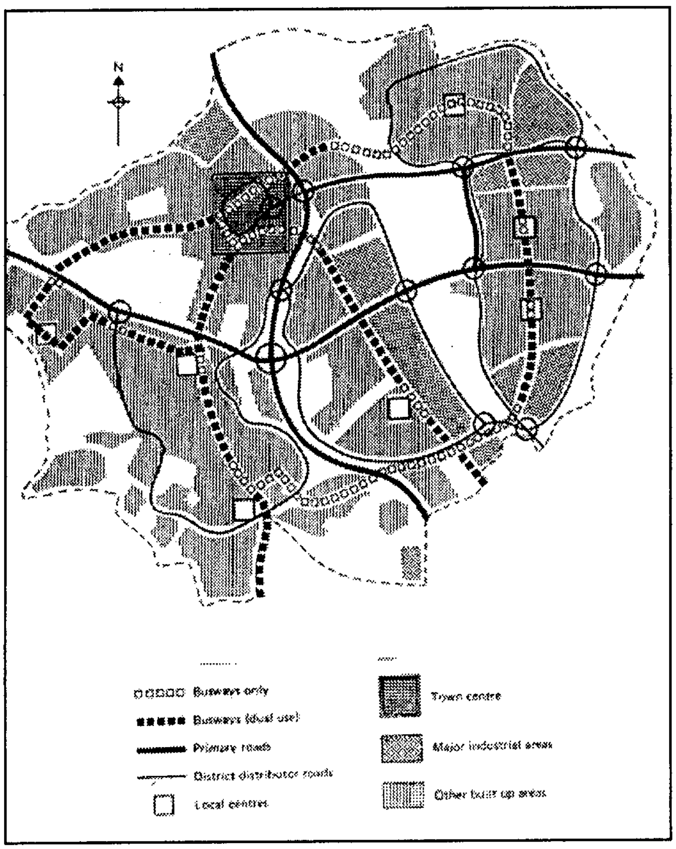


Figure 2.9 - Redditch Busway System

Plans for the busway were that buses would operate on an exclusive busway through the center of the villages and the main city. Private and commercial vehicles would be allowed to operate on the semi-exclusive sections with the buses (NATO 1976). As traffic approaches the various villages, all vehicles except buses would be forced off the semi-exclusive busway onto the normal distribution road system. This would provide a direct and continuous route for the public transport system. The design of the Redditch busway provides service stops within a walking distance of 10 - 12 minutes.

Construction cost was estimated at $9 million (1973 dollars), including the partial redevelopment of some existing roads to busway or semi-busway standards.

2.5 Evry, France

Located 16 miles (25.8 km) south of Paris, Evry is a new town that projected a population of 500,000 persons by 1990. Upon completion, Evry will be served by a 30-mile (48.3-km) busway, with another 25 miles (40.3 km) of bus routes operating in local traffic but connecting all parts of this planned city.

According to plans, the busway (**Figure 2.10**) will be fully grade-separated for 19 miles (30.6 km) and at-grade for the remaining 11 miles (17.7 Km). The operating speed on the busway will average 15 mph. An estimated 55 percent of all internal vehicle trips will be carried by the bus system. Approximately one-sixth of all daily vehicle trips end at the city center, this percentage will increase 20 - 30 percent during the peak hour, which will account for about 15,000 trips.

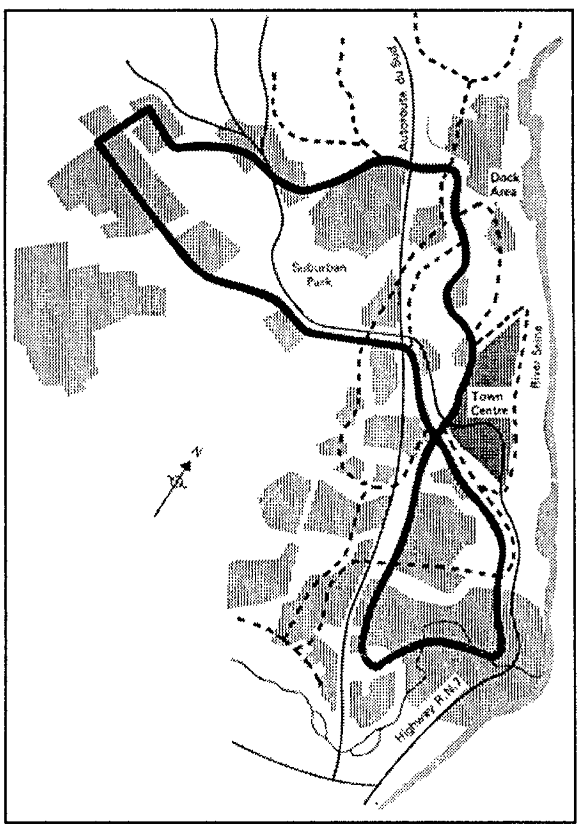


Figure 2.10 - Evry Busway System

Due to this heavy movement, the bus system was designed to be easily converted into an automated system which will allow buses to operate at high speeds and close headways to increase line capacity.

2.6 Curitiba Busway, Brazil

Curitiba is an ancient Brazilian city with 1.6 million inhabitants and a metropolitan population of 2.3 million. Due to its strategic location between the Atuba and Belem rivers, the population increased from 300,000 in 1950 to its current population of 2.3 million. This dramatic increase in population started in the 1960s. In 1970, Curitiba decided to address its urban and congestion problems. Due to the low initial cost of the busway and supporting land use legislation that encouraged high-density population, together with service and commerce in the areas adjacent to each busway, Curitiba developed a remarkable busway system, shown in **Figure 2.11 and 2.12**. The busway in Curitiba combined most of the advantages of a subway system at a low capital cost of approximately $0.32 million per mile ($0.2 million per km).

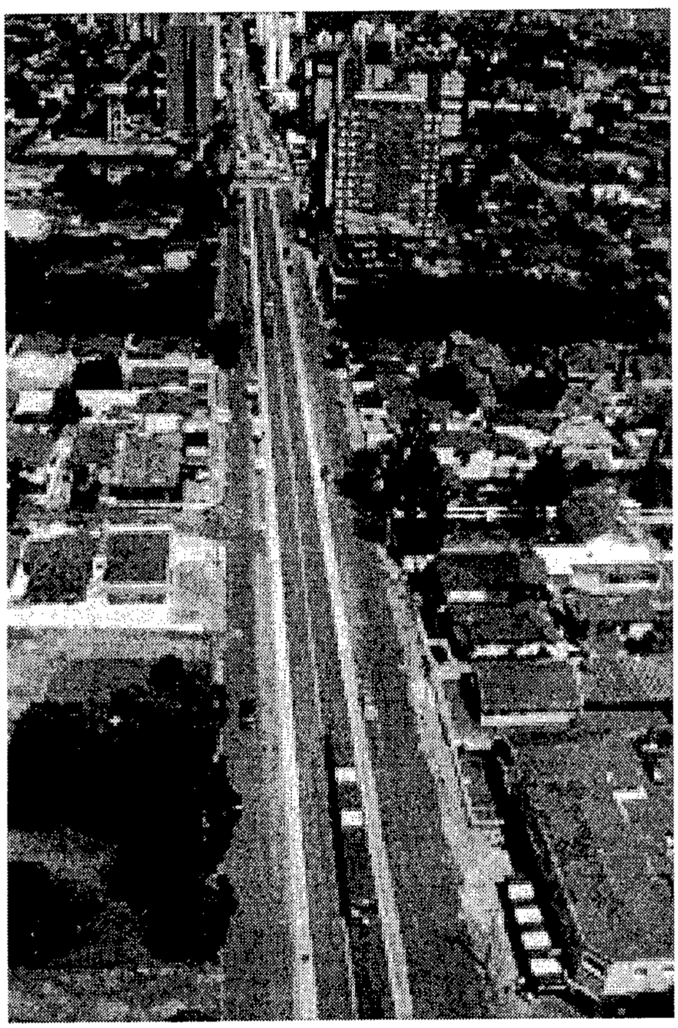


Figure 2.11 - Busway System in Curitiba

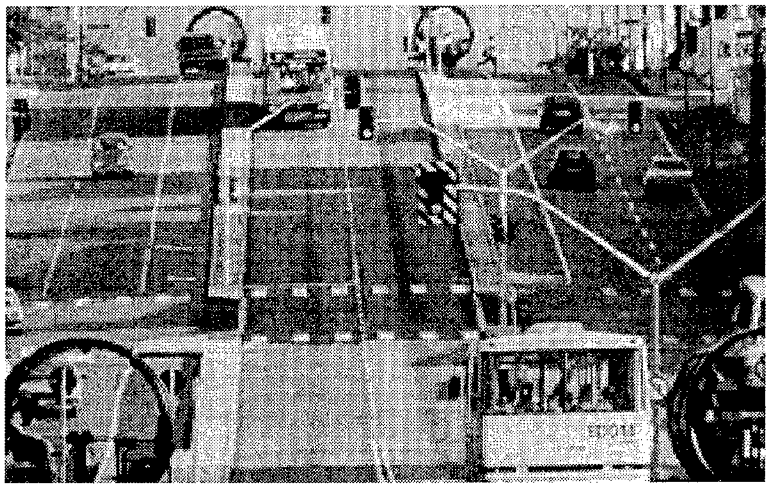


Figure 2.12 - Curitiba Busway Design

The Curitiba busway system consists of five main express lines (North, South, East, West, and Boguerira lines) with a total length of 34 miles (54.7 km) of exclusive roadway devoted for express buses. The busway runs in the median of a four-lane (two each direction) high-capacity arterial. The busway system in Curitiba is described as "trunk and branch" as it is flanked by local roads. The busway was designed to be fully integrated with other bus transit services in the city. Large bus terminals located at the end of each of the five busways allow the passengers to transfer to inter-municipal feeder buses. Along each busway, bus terminals are located in the median approximately two kilometers apart where passengers arriving at the terminals can transfer to other express buses, feeder buses, or inter-district buses. The intermediate terminals are equipped with newspaper stands, public telephones, post office, and small commercial facilities. Regular bus stops are also located along each of the busways and are 0.25 miles (0.4 km) apart.

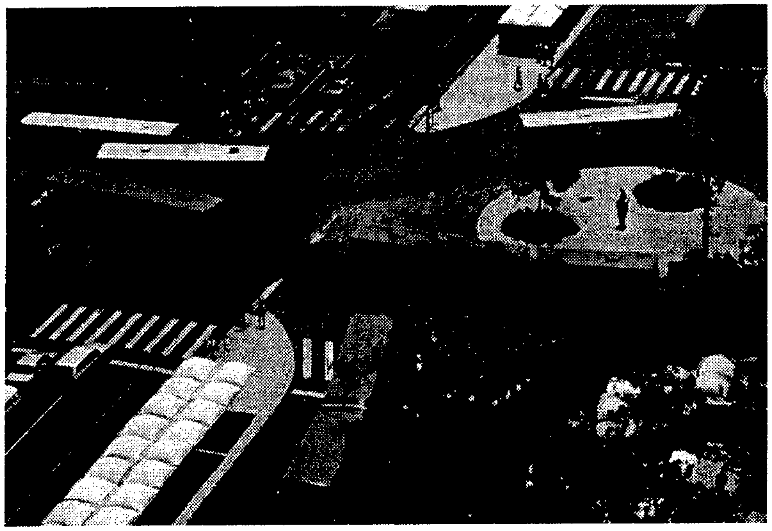


Figure 2.13 - Curitiba's Color Coded Bus Transit System

The City of Curitiba has a color-coded bus transit system as shown in **Figure 2.13**. The red color is assigned to the express buses running through the busway, the yellow color to feeder buses circulating through areas outside the central city, and the green color to inter-district buses that follow concentric routes linking neighborhoods.

This integrated trunk and branch system functions like a subway. Passengers pay one fare to get into the system where they can transfer between different routes. Enclosed terminals are constructed to separate transferring passengers from those who had not paid their fare. Stations have the same basic function as a subway station but are at surface level. Passengers are free to walk inside the terminals, shop, make phone calls, and transfer from one bus to another without having to pay another fare. People living near the terminal pay the fare when they enter the terminal through turnstiles.

The conventional bus is modified so that the door opens directly onto the innovative boarding tube station as shown in **Figure 2.14**. The floor from the bus to the boarding tube is leveled. Without stairs to climb or having to step onto uneven pavement, passengers board and alight quickly. Wheelchair lifts are also installed in these tubes rather than on the bus to increase the speed of boarding by bringing disabled passengers to the proper height before the bus arrives. About 1,100 buses make 12,500 trips per day, serving 1.3 million passengers, or 55 percent of the total transport demand in the city (Major 1997). In 1989, Curitiba's bus system accounted for 70 percent of the total weekday trips in the city. The bus system, comprised of 34 miles (54.7 km) of express bus aerial (busway) and nearly 310 miles (499 km) of feeder and inter-district bus routes, covers 65 percent of the municipality's area.

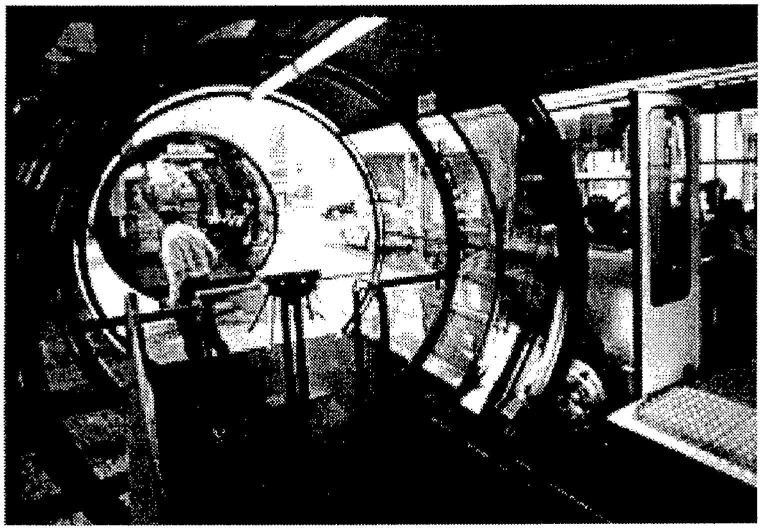


Figure 2.14 - Curitiba Busway Station

2.8 THE EL MONTE BUSWAY

The El Monte Busway is referred to as an L.A. success. It is one of the earliest and most successful bus/carpool priority schemes. Located in the nation's second largest metropolitan area and sixth largest central business district (CBD), the El Monte Busway was developed due to the region's increasingly congestive freeway system.

The El Monte Busway (Los Angeles I-10) known as the San Bernardino Freeway Express Busway, shown in **Figure 2.15** is a joint project between the Southern California Rapid Transit District (SCRTD), the Southern Pacific Transportation Company, the California Department of Transportation (Caltrans) and the Federal Government.

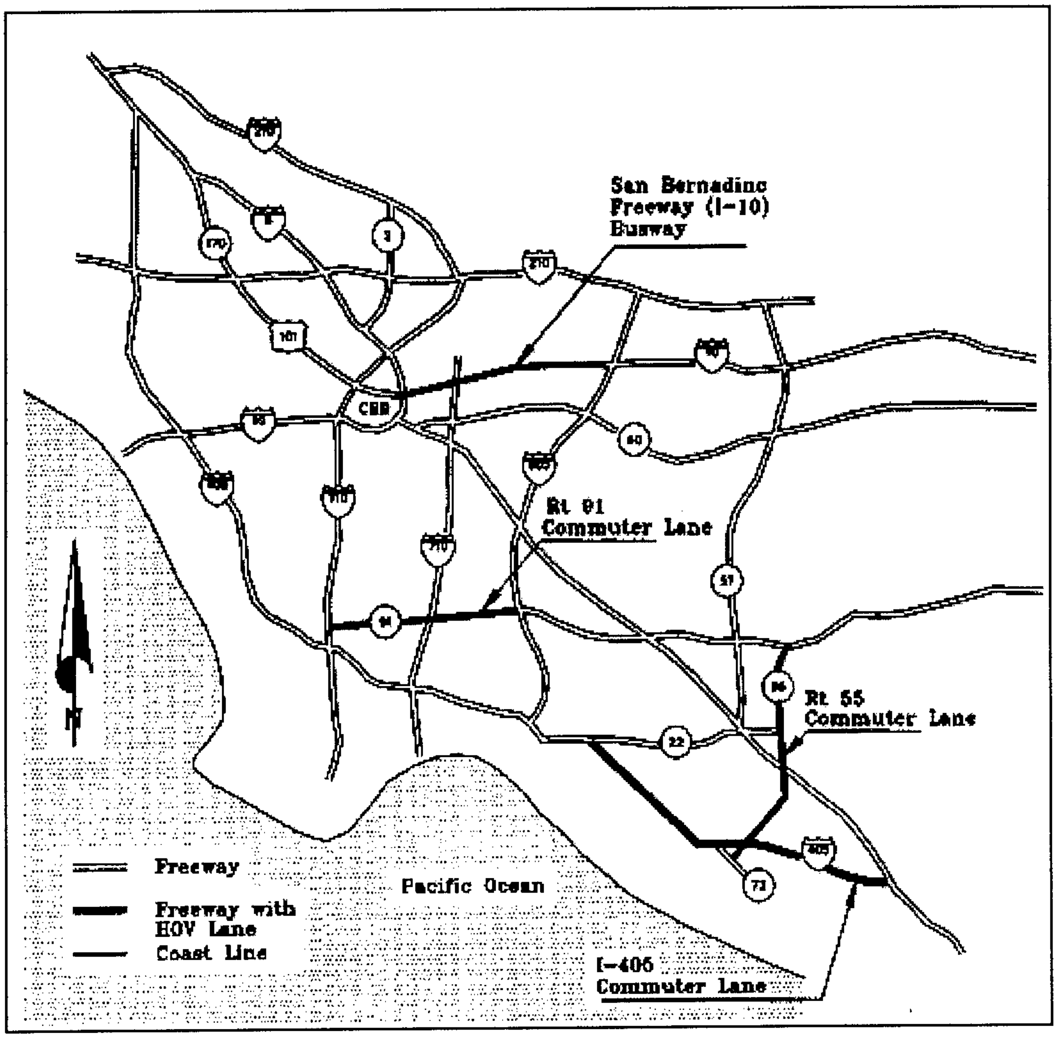


Figure 2.15 - San Bernardino Freeway (I-10) Busway

The El Monte Busway began operation in 1973 as a bus-only facility, but was converted to a bus/carpool facility in 1976. In 1996, the busway's ridership was approximately 12,000 persons during the AM peak period (6:30 - 8:30 AM) and 15,000 persons during the PM peak period (4:00 - 6:30 PM), (US DOT, Jan 1992). The El Monte Busway is a two-way, two-lane (one in each direction) exclusive HOV facility. This facility is approximately 11 miles (17.6 km) in length and extends west from the El Monte Bus Station which is equipped with a park-and-ride facility, to the Los Angeles CBD. Restrictions allowing buses, vanpools, and 3+ carpools to operate on the busway are in effect 24 hours a day.

The El Monte Busway consists of two distinct sections. The eastern (outermost) seven miles (11.2 km) of the busway is located in the median strip of the freeway. This section consists of one 17-foot (5.2 m) lane in each direction separated from the main lanes by 10-foot (3 m) paved shoulders with stanchions. The remaining four miles of the busway run parallel and adjacent to the north side of the freeway, and consists of two 25-foot (7.6 m) wide lanes separated from the freeway by a concrete barrier, as shown in **Figure 2.16**.

Figure 2.16 - El Monte HOV Lanes

The average traveling time savings on the busway for the entire peak period is 10 minutes. However, vehicles using the busway during the most heavily congested parts of the AM peak period can save up to 17 minutes in traveling time. During peak periods the average speed on the HOV lane is 52 mph (84 km/h), while the general freeway lanes average a speed of 26 mph (42 km/h). Therefore, it is evident that the El Monte Busway provides substantial time savings for 3+ carpools. Travel time savings for bus users depends on their method of access to the most convenient park-and-ride or bus stations and the time at which the trip was started.

Capital costs was approximately $9.6 million per mile, totaling $107 million (1989 dollars) for the entire 11 miles (17.6 km) of the busway, this is shown in **Table 2.7**. The average cost of operating a SCRTD bus on the El Monte Busway was $2.41 a mile, while the operating cost including station cost averaged $2.36 for the entire day and $1.89 during peak periods per passenger, costs are in 1989 dollars. Single trip fares in 1989 dollars were $0.59 per trip, but due to discounts for passes the average cost was $0.24 per trip. This resulted in only a small recovery of the operating costs of the El Monte express bus service from the fare box. As a result, almost 90 percent of per trip operating costs were covered by subsidies.

Accident rates per person-mile for vehicles using the busway has averaged 0.3 accidents per million person-miles, which is less than one-third of the value for the general purpose freeway (US DOT, Jan 1992).

Table 2.7 Capital Cost and Operating Cost for SCRTD Busway as of 1989

Category	Cost (1989 dollars)	
Capital Cost (million)	$	107.00
Capital Cost / mile (million)	$	9.60
Operating Cost / passenger / peak period	$	1.89
Operating Cost / bus per mile	$	2.41
Average Operating Cost / passenger / day including station cost	$	2.36
Single Trip Fare	$	0.59
Average Cost per Trip	$	0.24

Source: US DOT, January 1992.

2.8 THE SHIRLEY HIGHWAY (I-395)

The initial five miles (8 km) bus-only lanes on the Shirley Highway began operation in 1969 to encourage more extensive use of bus transit by Northern Virginia residents during peak periods to travel to and from work. The entire project was completed in 1975 and consisted of approximately 12 miles (19.3 km). The bus-only facility was designed to complement the regional rail rapid transit system which provides park-and-ride facilities with convenient access to Metrorail stations. The Shirley Highway and the current HOV facilities on Northern Virginia highways to Washington, D.C are shown in **Figure 2.17**.

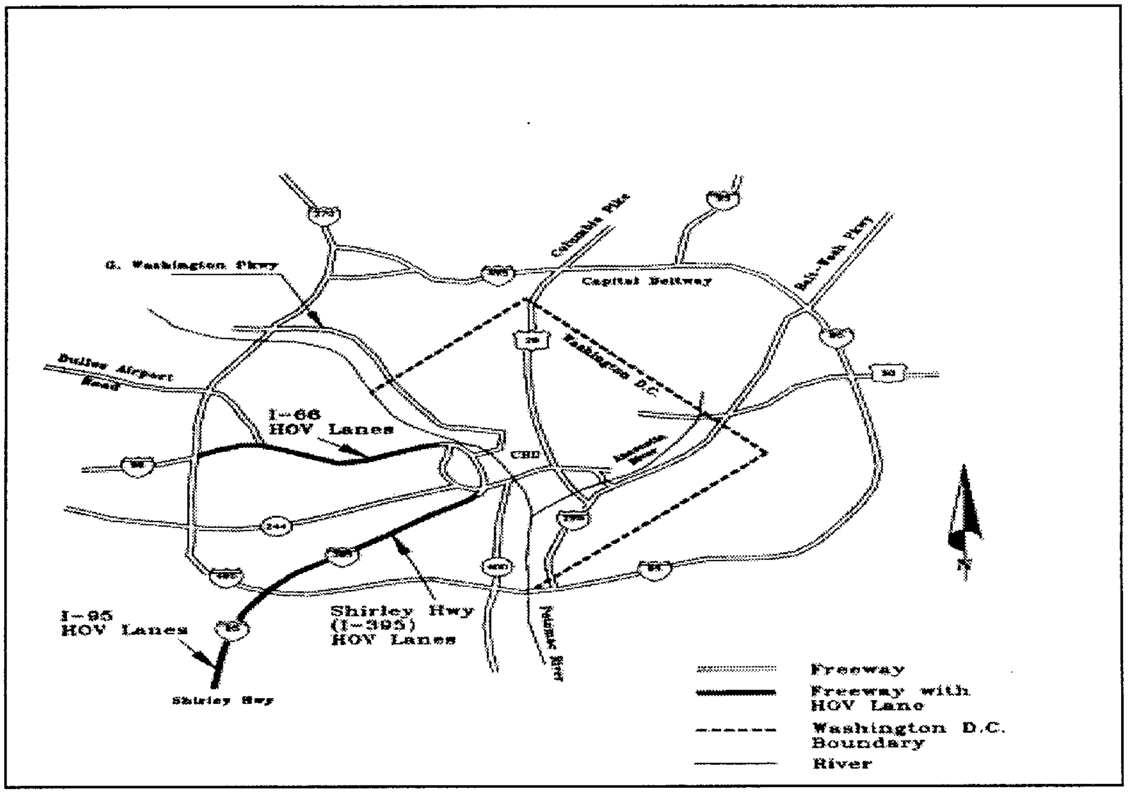


Figure 2.17 - Shirley Highway HOV Lanes

The Shirley Highway express lanes were originally designed as a two-lane, reversible HOV facility located in the median of the freeway and separated from general traffic by concrete barriers as part of a highway widening project. This project further converted the 4-lane, urban arterial (two lane each direction) roadway to an 8-lane freeway.

Implementation of the Shirley Highway express lanes was the first time that part of an interstate highway had been dedicated to exclusive bus use. The initial 5 miles (8.1 km) of exclusive bus lanes saved bus commuters from Northern Virginia 12 to 18 minutes per trip. Bus ridership on the Shirley increased dramatically from 3,800 AM peak period riders in 1969, when the facility first opened, to 4,500 in 1970, and 9,000 by 1971.

In April 1971, the permanent Shirley Highway HOV lanes were extended to their present 15 miles (24.1 km) in length, including bus-only lanes on the 14th Street Bridge. At this time, the Shirley Highway project became part of a joint FHWA and UMTA "bus-on-freeway" demonstration project. This project's goal was to determine how suburban commuters would respond to high-speed, quality bus service.

Only buses were allowed to use the facility during the first four years of operation. In December 1973, the HOV lanes were opened to vanpools and carpools with 4+ passengers, but in January 1989, the Shirley Highway was downgraded to 3+ passengers. During the last 20 years of operation of the Shirley Highway HOV lanes, carpooling and bus passengers using the facility during peak periods have saved approximately 15-20 minutes per trip. During the peak periods, traffic moves freely on the HOV lanes at a speed of 55 mph, while speeds in the adjacent general traffic lanes average 19 mph to 33 mph during the AM peak and 27 mph to 49 mph during the PM peak periods.

The typical width of the express lanes are 12 feet (3.7 m) wide with two 10 foot (3 m) shoulders on each side. The HOV lanes on the Shirley Highway are shown in **Figure 2.18**. Buses and carpools enter and leave the Shirley Highway at several T-ramps and slip ramps. There are six northbound entrances and six southbound exits along the Shirley Highway. Similarly, there are six southbound exits and four northbound entrances. The HOV lanes operate one-way northbound between 11:00 p.m. and 11:00 a.m. and one-way southbound between 1:00 p.m. and 8:00 p.m. The lanes are closed to all traffic from 8:00 p.m. to 11:00 p.m. and between 11:00 a.m. and 1:00 p.m. to allow for reversing the direction of traffic flow on the facility. The use of the express lanes has been restricted to vehicles with three and more (3+) occupants from 6:00 a.m. to 9:00 a.m. and from 3:30 p.m. to 6:00 p.m. as an experiment to determine the best corridor occupancy level.

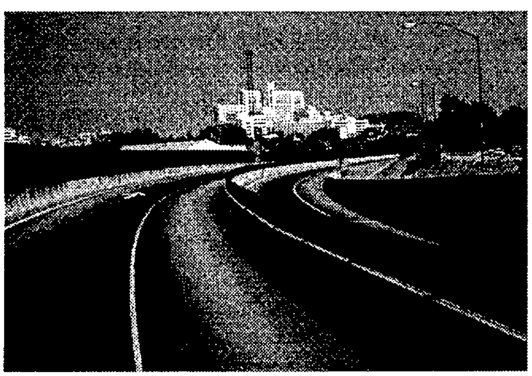
There is a permanent park-and-ride lot at Huntington station directly off the highway where commuters can transfer to the Metrorail Yellow Line.

The Shirley Highway is the oldest and most intensively used of the three HOV facilities in the Washington, D.C. metropolitan area (Shirley Highway, I-66 HOV Parkway, and I-95 Diamond Lanes). Over 500 buses carried nearly 19,000 passengers during the morning peak period on the three North Virginia HOV facilities in May 1988, this is shown in **Table 2.8.** A segment of the Shirley Highway's two physically segregated reversible express lanes located in the highway median began operating in September, 1969 as exclusive bus lanes.

Table 2.8 - Northern Virginia to Washington D.C. AM Peak Period and Peak Hour Person and Vehicle Trips by Facility

Time and Facility	Vehicles		Persons		Per Lanes Hour		Auto Occupancy Rates
	Total	Buses	Total	Buses	Vehicles	Persons	
Peak Hour (6:45 - 7:45 AM)							
Shirley Express Lanes	2,279	179	16,526	6,265	1,140	8,263	4.9
I-66 HOV Lanes	1,683	19	5,795	665	819	2,898	3.2
I-95 HOV Diamond Lanes	1,516	42	7,153	1,470	1,516	7,153	3.9
Total (5 HOV lanes)	**5,433**	**240**	**29,474**	**8,400**	**1,087**	**5,895**	**4.1**
Peak Period (6:00 - 9:00 PM)							
Shirley Express Lanes	4,835	402	32,908	14,070	806	5,485	4.2
I-66 HOV Lanes	3,945	49	11,876	1,715	789	2,375	2.6
I-95 HOV Diamond Lanes	3,819	81	13,815	2,835	1,273	4,605	2.9
Total (5 HOV lanes)	**12,599**	**532**	**58,599**	**18,620**	**900**	**4,186**	**3.3**

Source: Virginia Department of Highway and Transportation, May, 1988.



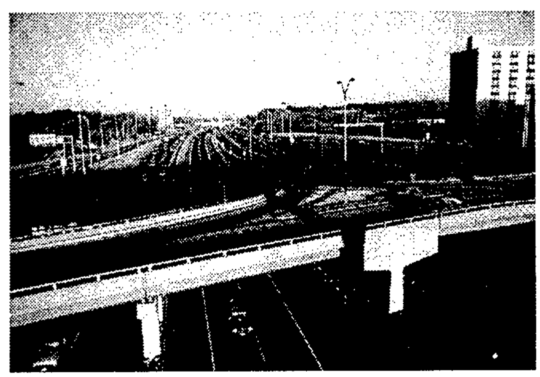


Figure 2.18 - Shirley Highway HOV Lanes

2.9 HOUSTON'S TRANSITWAYS

Houston's evolving express bus and transitway system is the most aspiring and innovative effort to provide suburban residents with high-performance, high-speed, and cost effective commuter services implemented by any North American city since World War II (US DOT, Jan 1992). Federal capital subsidies and revenues from a one percent sales tax enabled the Metropolitan Transit Authority of Harris County (METRO) to independently construct the 95 miles (152.9 km) of transitways shown in **Figure 2.19**, and at the same time maintain low fares while expanding local bus services.

Houston's transitways are physically separated, reversible, one-lane roadways built in the median of radial expressways. The transitways are generally used by buses, vanpools, and 2+ or 3+ carpools depending on transit demand, with the exception of the North Transitway 19.7 mile (31.7 km) facility used only by buses and authorized vanpools. A representation of the daily ridership on these HOV lanes is shown in **Table 2.9**. All HOV lanes operate from 5:00 a.m. to 12:00 noon (Inbound) and from 2:00 p.m. to 9:00 p.m. (Outbound) during the week day.

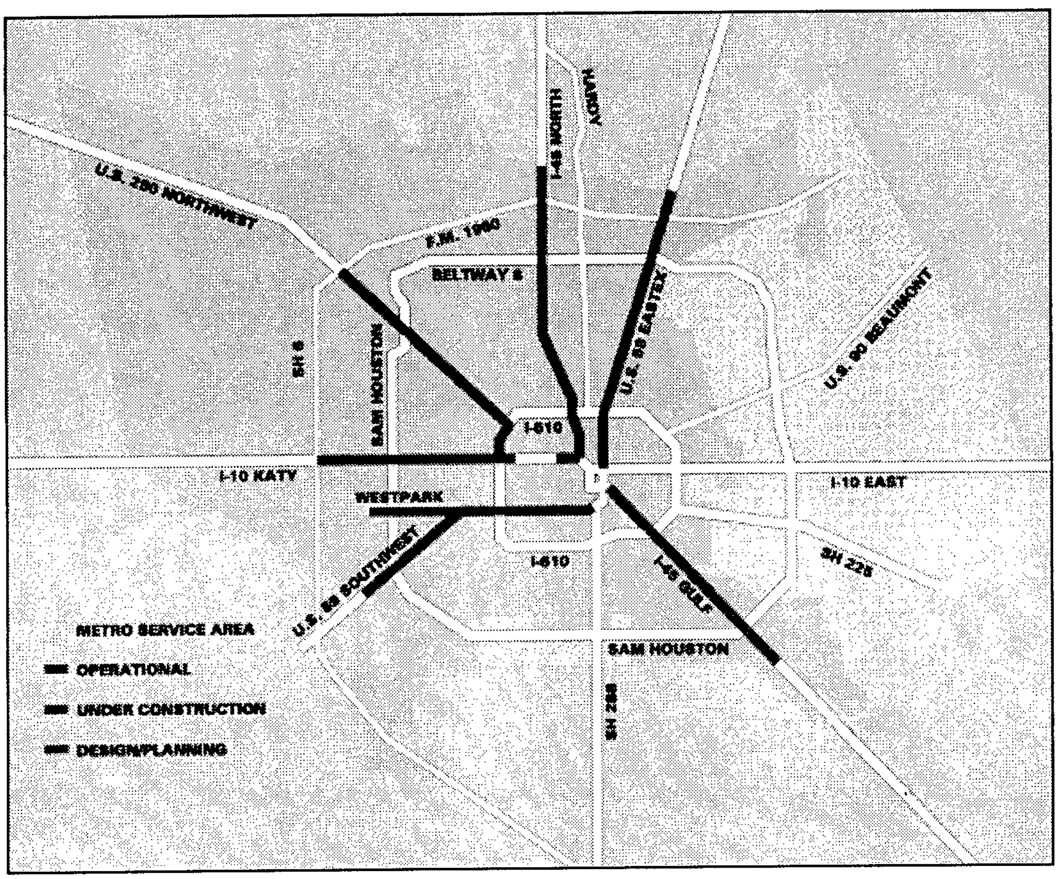


Figure 2.19 Houston's HOV Lanes

The North Freeway AVL

The North Freeway Authorized Vehicle Lane (AVL) was the first of Houston's transitways. The construction of this transitway was carried out in four phases as part of a broader North Freeway (IH-45) Improvement Project (US DOT, Jan 1992). The North Transitway is projected for completion in 1997, resulting in a 19.7 mile (31.7 km) barrier separated roadway located in the median of IH-45N that extends from downtown Houston to Farm Market Highway (FM 1960). Presently, only 13.4 miles (21.6 km) of the North Freeway AVL is in operation. There are five park-and-ride lots located along the AVL.

The Katy Transitway

The Katy Freeway HOV lane located on the I-10 West, serves the major travel corridor in the west side of the city of Houston. The 13 mile (20.9 km) one-lane, barrier separated, reversible HOV lane is located in the freeway median. Three park-and-ride and three park-and-pool lots are located along the corridor. Access and egress is provided by both slip ramps and direct access ramps.

Capital cost for the 13 mile (20.9 km) Katy Transitway was approximately $50.4 million ($3.9 million per mile 1989 dollars), including the 1.5 mile (2.4 km), $6.1 million (1989 dollar) Katy Transitway Eastern Extension. The transitway began operation in October 1989. The completed transitway is 19.5 feet (5.9 m) wide and consists of one 12 foot (3.7 m) HOV lane and a 3.75 foot (1.1 m) shoulder on either side separated from the freeway by concrete barriers.

The Katy HOV Lane is the only HOV lane in Houston that has weekend operation. The lane is open in the inbound direction from 5:00 a.m. to 9:00 p.m. on Saturday, while on Sunday it is open in the outbound direction from 5:00 a.m. to 9:00 p.m.. This HOV lane is also the only HOV lane that has a restriction of 3+ carpool during 6:45 a.m. to 8:00 a.m. and 5:00 p.m. to 6:00 p.m., all other times are 2+ carpools. The traffic conditions before and after the construction of the Katy HOV lane are shown in **Figure 2.20**.

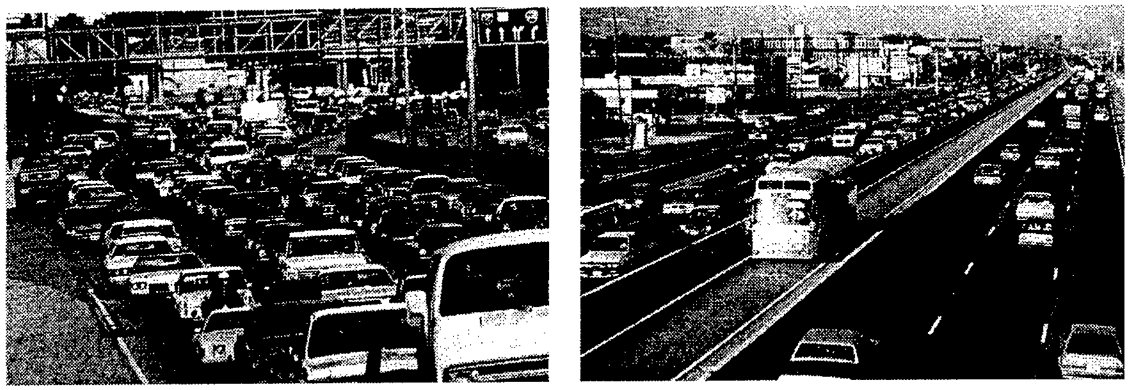


Figure 2.20 - Traffic Conditions Before and After the Construction of Katy HOV Lanes

The Gulf Transitway

The Gulf Transitway is a barrier separated, one-way, reversible HOV lane in the median of the Gulf Freeway (I-45 South) from downtown Houston to Choate Road. The transitway was developed as part of the SDHPT's (State Department of Highways and public Transportation) project to widen the freeway. The Gulf Transitway extends for 15.5 miles (24.9 km) and is used by buses, vanpools and 2+ carpools. Approximately 11.6 miles (18.7 km) are presently in operation and there are 3 park-and-ride facilities located along the HOV lane. The first 6.2 miles (9.9 km) of the transitway began operation in 1988, this section extends from Lockwood to Broadway and included an elevated Eastwood interchange T-ramp. Elevated interchanges provide access to one park and ride facility, two vanpool staging areas and the Lockwood transit center, these access points provide further access to places such as downtown Houston, the University of Houston and Monroe Road leading to Hobby Airport. Access to the Gulf Transitway is provided by T-ramps and at-grade ramps.

The Northwest Transitway

The Northwest Transitway is a 13.5 mile (21.7 km) HOV lane built in the median of the Northwest Freeway (US- 290), at an estimated total cost of $125.1million (1989 dollars). The transitway extends from just east of FM 1960 to I-10 (Katy Freeway) and is used by buses, vanpools and carpools. Vehicles began operating on the Northwest Transitway in August 1988. Approximately 10.5 miles (16.9 km) are at-grade, while the remaining three miles (4.8 km) are elevated. The at-grade segment of the transitway is a 20 foot (6.1 m) one-lane reversible HOV lane within the median of US-290. The elevated segment is a two-lane, two-way 38-`foot (11.6 m) wide configuration from loop I-610 to the Northwest Transit Center. The aerial segment of the transitway provides direct, grade separated, controlled ramp access to three of the four existing park-and-ride lots along the corridor. Access is also provided to the Brookhollow Office Complex, and the Northwest Transit Center.

The Southwest Transitway

The Southwest Transitway is a 20.5 foot (6.2 m) wide, one lane reversible facility built in the median of the Southwest Freeway (US 59). The transitway was built as part of a project that would widen and improve the freeway (US 59), from Beltway 8 to State Highway 288 (SH 288). The transitway extends for 11.6 miles (18.7 km) and is equipped with seven park-and-ride lots. Users will be able to enter or leave the transitway at seven locations including one in downtown Houston. All ramps along the transitway have been designed to facilitate two-way operation. Types of access used in the design of the transitway includes park-and-ride lots, slip ramps, freeway access/egress ramps, at-grade ramps, and grade separated T-ramps.

The Eastex Transitway

The Eastex Transitway is a new addition to Houston's transitway development program, and is being built in conjunction with the reconstruction of the Eastex Freeway.

The transitway as shown in **Figure 2.19** will consist of a 20 mile (32.2 km) two lane, two way HOV lane from downtown Houston to Kingwood Drive. The HOV lane will be completed in three phases, a 10.7 mile (17.2 km) segment, a 3.5 mile (5.6 km) segment, and a 5.8 mile (9.3 km) segment, respectively. As proposed, operation of the Eastex Transitway started in 1994. Seven access points are provided to the Eastex Transitway including one in downtown and another at Kingwood Drive. The facility is also equipped with 3 park-and-ride lots.

Table 2.9 - High Occupancy Vehicle Lane Summary as of September, 1996

Measure	Katy HOV Lane		North HOV Lane		Gulf HOV Lane		Northwest HOV Lane		Southwest HOV Lane	
	Vehicles	Persons	Vehicles	Persons	Vehicles	Persons	Vehicles	Persons	Vehicles	Persons
A.M. PEAK PERIOD										
Buses	76	2,600	100	3,685	66	1,920	36	1,425	58	1,690
Vanpools	63	491	76	595	17	124	21	84	21	154
Carpools	2,284	5,090	2,573	5,415	1,754	3,645	2,596	5,150	2,511	5,169
Motorcycles	21	21	0	0	8	8	18	18	8	8
Total	**2,444**	**8,202**	**2,749**	**9,695**	**1,845**	**5,697**	**2,663**	**6,669**	**2,598**	**7,021**
P.M. PEAK PERIOD										
Buses	101	2,890	115	3,720	63	1,650	41	1,655	74	2,140
Vanpools	22	185	53	280	18	156	19	143	14	91
Carpools	2,350	5,155	2,559	5,132	1,825	3,855	2,186	4,489	2,212	4,721
Motorcycles	43	43	18	18	5	5	21	21	8	8
Total	**2,516**	**8,273**	**2,745**	**9,150**	**1,911**	**5,666**	**2,267**	**6,308**	**2,308**	**6,960**
TOTAL DAILY										
Buses	177	5,490	215	7,405	129	3,570	77	3,080	132	3,830
Vanpools	85	676	129	875	35	280	48	227	35	245
Carpools	6,061	13,099	5,670	11,623	3,912	8,166	4,987	10,049	5,344	11,132
Motorcycles	61	64	18	18	13	13	31	31	16	16
Total	**6,387**	**19,329**	**6,032**	**19,921**	**4,089**	**12,029**	**5,135**	**13,387**	**5,527**	**15,223**

Source: Houston High-Occupancy Vehicle Lane Operations Summary, Volume - Passenger Utilization Quarterly Report, September 1996.

3. LIGHT RAIL SYSTEMS

The operation of busways is similar to that of the light rail transit systems. Both busway and LRT can have similar alignments. They can be placed either in the median or on the side of the road. A series of combinations of busway and LRT right-of-way alignments are shown in **Figure 1.1** of the introduction section and **Figure 3.1** shown below, respectively. Busways can inherit some of the operation characteristics of the LRT. A comparison between the busway and LRT characteristics is shown in **Table 3.1**. Although the capacity of the LRT is double that of the busway, both systems display a high level of reliability. The two systems have also a good relationship with other modes and therefore make transfers easier for passengers. The average trip length on a busway is short to long while the average LRT length is medium to long. In comparing the network coverage of both systems, the busway has good radial but limited CBD coverage while LRT has fairly good coverage of central areas (either in tunnels, elevated, or on at grade separated rights-of-way) with extensions branching out at-grade on a number of radial routes (Vuchic 1981).

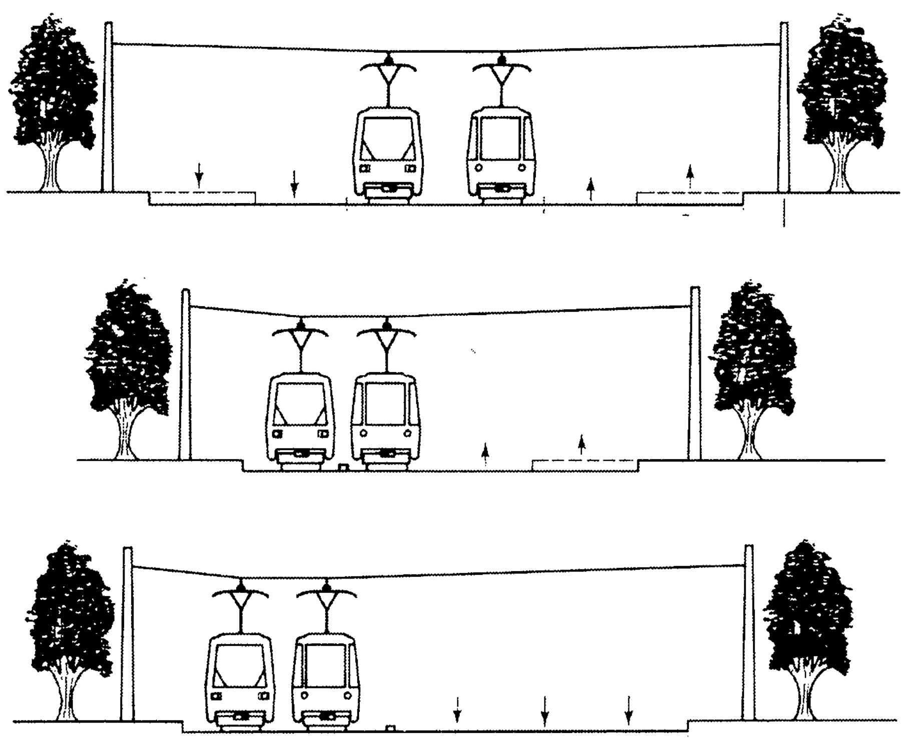


Figure 3.1 - Different LRT Track Positions in Street Roadways

Table 3.1 - Comparison of Characteristics between At-grade Busway and Rail Transit Modes

Characteristics	At-grade Busway	Light Rail
Bus/Train Characteristics		
Minimum Consist	1	1 (4-axle)
Type of bus/train composition	minibus / full size / articulated / double[a] articulated	2-4 (6-8-axle)
Vehicle length (m)	25 / 40 / 60 / NA	14 -30
Vehicle capacity (seats per vehicle)	25 / 53 / 73 / NA	25 - 80
Vehicle capacity (total spaces per vehicle)	40 / 85 / 110 / 270	110 - 250
Fixed Facilities		
Exclusive right-of-way (% of length)	40 - 90	40 - 90
Vehicle control	Manual/visual	Manual/automatic
Fare collection	On vehicle/at station	On vehicle/at station/honor
Power supply	Internal Combustion Engine	Overhead
Stations Platform height Access control	 Low or high[a] None or full	 Low or high None or full
Operational Characteristics		
Maximum speed (km/h)	70	60 - 120
Operating speed (km/h)	40	18 - 40
Maximum frequency Peak hour, joint section (TU/h) Off-peak, single line (TU/h)	 2 - 120 15	 40 - 90 5 - 12
Capacity (prs/h)	2,000 - 10,000	6,000 - 20,000
Reliability	High	High
System Aspects		
Network and area coverage	Radial / limited CBD coverage	Good CBD coverage branching is common
Station spacing (m)	430 - 700	350 - 800
Average trip length	Short to Long	Medium to Long
Relationship with other modes	LRT, RRT, P+R, K+R, Feeder Bus	P+R, K+R, Feeder Bus possible

LRT = Light Rail Transit. RRT = Rapid Rail Transit. P+R = Park and Ride.
K+R = Kiss and Ride. TU= Transit Unit.
(a) Only used in Curitiba, Brazil.

In this section of the report, 10 LRT systems operating in city streets are presented as of Korve 1996. These LRT systems operate in either exclusive, semi-exclusive, or share right-of-way. A brief description of each system is provided along with signal control systems, accident experience, and actions taken by each transit agency to improve the safety of its system.

3.1 Baltimore, Maryland

Approximately two miles (3.2 km) of the 22-mile (35.4 km) Baltimore Center Light Rail Line is operated in the downtown area within a street right-of-way along Howard Street at a speed of 15 mph (25 km/h). The other sections operate in exclusive or semi-exclusive rights-of-way at average speeds above 35 mph (56 km/h).

At the downtown section, LRT signals displaying a white bar aspect are used to control LRVs on Howard Street. These signals are mounted on two pedestrian signal heads located on the far side of the intersection. The bottom LRT signal indication displays two horizontal bars requiring the LRV operator to stop, while the top indication displays either a vertical bar advising the LRV operator to proceed or a slanted bar indicating that the LRT signal is about to change to a stop indication. Parallel and cross-street motor vehicle traffic in a shared right-of-way is controlled by standard traffic signals.

Most of the traffic problems occur in the downtown area along Howard Street. Of particular concern are the motor vehicles that operate parallel to LRVs on Howard Street and make left turns across the LRT tracks.

Accident information indicates that 50% of the accidents involved automobiles, 36% involved trucks or buses, 11% involved pedestrians, and the remaining 3% are otherwise defined. The 2 miles (3.2 km) of street running in the central business district (CBD) accounted for 89% of the total accidents, while the remaining 11% occurred along the 20 miles (32.2 km) of operation on a semi-exclusive right-of-way.

3.2 Boston, Massachusetts

The Massachusetts Bay Transportation Authority (MBTA) Light Rail is one of the oldest in the United States. The MBTA Green Line consists of four services (B Line, C Line, D Line, and E Line) totaling 25 miles (40 km) of routes. 37% of the Green line operates are in a semi-exclusive right-of-way at a speed above 35 mph (55 km/h), 39% are within a street median, and 4% are in mixed traffic. The D Riverside line operates on a semi-exclusive right-of-way, where there are no vehicle grade crossings, but pedestrians cross the tracks at stations. The other three routes operate within a street median right-of-way, except for about the last mile of the E Brigham Circle line, which operates in mixed traffic. LRV can operate at a maximum speed of 25 - 30 mph (40 - 50 km/h) in both a mixed traffic and street median, but due to traffic signal delays, frequent stops for traffic, and posted speed limits, the actual speed is considerably lower.

LRVs have their own signals, usually mounted on the same poles as traffic signals. The signals are standard red, yellow, and green ball indications with a TROLLEY SIGNAL sign, a T-SIGNAL sign, or an MBTA SIGNAL sign placed below. Some of the LRT signals are optically programmed. Parallel and cross-street traffic is controlled by standard traffic signals and signs.

B-Line: Tracks are separated from the roadway by curbs, and a fence is located between the double set of tracks. Street crossings are spaced about 740 feet (225 m) apart through residential and commercial areas. Two-car LRV consists operate at a 5-minute peak headway and 7-10 minutes for off-peak periods.

C-Line: 5.6 miles (9 km) section of the route operates two-car LRVs in the median at a frequency of 7-8 minutes during peak and 6 - 10 minutes during off-peak periods. Street crossings are spaced about 740 feet (225 m) apart.

D-Line: The 11.9 miles (19.1 km) were a former commuter rail line. It consists of several pedestrian grade crossings at or near the stations. The three car consists operate on five minutes headway during the peak at a maximum speed of 50 mph (80 km/h).

E-Line: It is a 5.3 mile (8.5 km) line operating two-car consists of a headway of 6-8 minutes in a subway from Copley Street to Northeastern University. Between Brigham Circle and Health Street, LRVs operate within a street median, and in mixed traffic along Huntington and South Huntington Avenue. Street crossings are spaced about 1,050 feet (320 m) apart.

Tracks and passengers' platforms are separated from the roadway lanes by barrier curbs. Fences between the double set of tracks are provided on several sections of the line.

For the most part, motorists are familiar with the LRV routes, so the element of surprise common to newer systems is much less prevalent. The differential speed between LRVs and vehicles also limits the possibility of serious accidents.

Most of the problems occur due to the following:

- Illegal left turns at major junctions where turns are prohibited.
- Narrow station platforms at several locations.
- Motorists' disregard for traffic signals.
- Complex and irregular street patterns.
- Intersection offset, multiple approached, or obliquely angled.
- The placement of LRT and traffic signals varies from intersection to intersection and in some instances signals appear to be insufficiently separated.

- LRT signals having the same color, shape, indications, and placement as the general traffic signals are virtually indistinguishable.
- YIELD TO TROLLEY signs on turns are too small to be effective.
- There are no active signs to warn motorists of an approaching LRV at unsignalized vehicles and pedestrian crossings.
- Narrow passenger safety islands at some locations are routinely traversed by motorists.

Actions taken by MBTA include the following:

- Eliminating the side-of-the-road running by relocating some portions of the tracks in the center of the main roadway.
- Concrete barriers will be provided to separate the tracks from the main travel lanes.
- Providing protective left-turn lanes.
- Improving the intersection geometry.

3.3 Buffalo, New York

The 6 mile double track Buffalo light rail system, opened in 1985, operates at-grade within the CBD and in a subway outside the CBD. Within the 1 mile CBD portion, LRVs operate in a pedestrian transit mall right-of-way with low station platforms located in a center median. The two to three-car LRV consists operate at six minute headways during the peak periods. Along the CBD portion, there are eight at-grade intersections, 900 feet (275 m) apart and protected with preemption LRV traffic signals.

The two main concerns that account for most of the accidents in Buffalo are:

1. Motorists who are aware that LRVs travel at a relatively low speed try to beat the LRV through the intersections.
2. Motor vehicle queues back up and stop on the tracks blocking the LRVs during the rush hours.

3.4 Calgary, Alberta (Canada)

Calgary Transit's 18 mile LRT system consists of two lines. Both lines (201 and 202) operate in the Seventh Avenue transit mall where the tracks are located in the two center lanes of the four-lanes wide mall. Articulate LRVs operate in three car consists of two minute peak headways at a listed speed of 25 mph (40 km/h). Due to close distances of 580 feet (177 m) between the crossings, the average operating speed is 10 mph (16 km/h). Crossings are protected by standard traffic signals for LRVs, buses, and cross street motor vehicles. The transit mall is shared with buses, which use the same lane as the LRVs when passing stations. Grade crossings are also protected with standard automatic gated and flashing light signals.

Most of the accidents occurring in the transit mall are due to the following:

1. Motorists failing to comply with traffic signals at cross-street intersections accounted for 77% of the accidents.
2. Pedestrians disobeying pedestrian signals and jaywalking, crossing the tracks at mid-block without looking at both directions results in 23% of the accidents.

3.5 Los Angeles, California

Los Angeles County Metropolitan Transportation Authority (LACMTA) operates the 22 miles (35.4 km) Metro Blue Line between downtown Los Angeles and downtown Long Beach. The route contains almost 1 mile (1.6 km) of subway, 6 miles (9.7 km) of a semi-exclusive segment, where LRVs operate at 35 mph (55 km/h), and 15 miles (24.1 km) of a semi-exclusive segment, where LRVs operate at 55 mph (90 km/h). The maximum speed on the shared right-of-way segments which traverse 72 street crossings is 35 mph (55 km/h). The LRVs are governed by LRT signals with "T" aspects mounted in a standard horizontal traffic signal head next to general traffic signals.

In shared rights-of-way, parallel and cross-street motor vehicle traffic is controlled by standard traffic signals and signs. Most grade crossings located on the high-speed segment carrying high traffic volumes are protected with standard automatic gates and flashing light signals.

55% of the accidents involved a left-turn collision, 13% involved pedestrians, and 10% involved motor vehicles running around crossing gates. Accidents mainly occur due to the confusion of motorists and pedestrians by the two-way, side aligned LRT operation on Flower Street.

3.6 Portland, Oregon

The 15 mile (24.1 km) LRT system in Portland, operated by TRI-MET, is known as the MAX. The downtown portion consists of two sections. First, in the loop portion of the downtown, the LRVs operate one way on the left side of the street, parallel to vehicular traffic, at a typical speed of 15 mph (25 km/h). LRT tracks are not physically separated from vehicle lanes, but motorists are not allowed to drive on the tracks between crossings. In this portion, the signals are a progression in the LRVs' favor. Second, LRVs operate both ways in the median and side aligned on First Avenue in semi-exclusive and pedestrian mall alignments.

Headways on the line are about 7.5 minutes during the peak hours, ranging to 15 minutes during the off-peak hours. Typically, two-car consists operate at all times except during evenings and sometimes on Sundays one-car is used.

LRVs in shared rights-of-way are governed by two-section LRT signals displaying a bar aspect. A yellow horizontal bar is located on the top signals as an indication to stop along with a white vertical bar on the bottom of the signal as an indication to proceed. The white bar flashes when the LRT signal is about to change from proceeding to stop indication, similarly, the yellow horizontal bar flashes when the signal is about to change from stop to proceed indication. In the downtown area, the LRT signals are either mounted on the far side of the intersection above the traffic signals or mounted on a catenary support pole between the two tracks. Parallel and cross-street traffic in downtown is controlled with standard traffic signals and signs.

Most of the safety concerns on the Portland LRT system results from motorists failing to comply with traffic signals and signs. 41% of the accidents involved vehicle turns in front of the LRVs, 39% involved right-angle collisions, and 15% involved pedestrians.

3.7 Sacramento, California

The 18 miles (29 km) LRT system in Sacramento consists of two sections extending from the northeast suburbs through downtown and out to the southeast suburbs. Because Sacramento uses a wide variety of alignments, there are a number of unique design treatments. 21% of the total route is a nonexclusive alignment, 3% is exclusive, and the rest are semi-exclusive.

In the shared right-of-way, LRVs are governed by one or two LRT signals mounted on a mast arm on the far side of the intersection. LRT signal aspects consist of either one white, or one yellow, or one white and one yellow depending on the location and alignment type. Parallel and cross-street traffic in a shared right-of-way is controlled using standard traffic signals and signs. NO RIGHT/LEFT TURN signs are installed at crossings where LRT tracks are side aligned. The signs use two pedestrian-type signal heads with red words over a black background.

The typical speed for the LRVs is 20 mph (32.2 km/h) in the LRT/pedestrian mall, while in the shared right-of-way the speed is 30 mph (50 km/h). LRVs operate at 30 minutes headway during the morning and early evening and decreases to 15 minutes during the rest of the day.

The three main safety concerns in Sacramento are:

1- Pedestrians trespassing on the LRV tracks as it represents 3% of the accidents.
2- LRV-motor vehicle left-turn collision which represents 59% of the accidents.
3- A two-way side aligned LRT operation is responsible for righting angle collisions and represents 38%.

3.8 San Diego, California

The East and the South lines in San Diego are operated by San Diego Trolley, Inc. The South line LRT system is 15 miles (24.1 km) long and the LRV consists of three cars operating at an average speed of 35 mph (55 km/h) at 15 minutes headway. The headway decreases during the peak period to 10 minutes, while it increases to 30 minutes on nights and weekends.

The 15 mile (24.1 km) East line runs along a semi-exclusive right-of-way alignment. LRVs operate in the median of Commercial Street between 12th and 32nd Street, and share tracks on a semi-exclusive right-of-way with the San Diego Imperial Valley Railway between 32nd Street and El Cajon.

The Center City segment is common to both lines and covers about 1.5 miles (2.41 km) from the system's America Plaza Transfer Station to the Imperial/12th Avenue station. In the Center City segment, LRVs run in both a semi-exclusive alignment and pedestrian/transit mall. The semi-exclusive portion is about 85% of the Center City segment and the rest is the pedestrian/transit mall.

LRVs in shared rights-of-way are governed by standard signals, which also control parallel traffic. Along Commercial Street, LRV signals consists of one-head green "T" mounted on a mast arm. The green "T" illuminates when an LRV preempts the motorists' traffic signal. Other locations in the downtown LRT signal indication is a white "T" which has the same function as the green "T".

Parallel and cross-street traffic in shared right-of-way under 35 mph (55 km/h) is controlled by standard traffic signals and signs. NO RIGHT TURN with internal illumination is used at the intersections of Broadway and Kettner Boulevard.

About 85% of the accidents involve motor vehicles and the remaining accidents involve pedestrians. The three main safety concerns in San Diego are:

1- Motorists driving on tracks.
2- Motorists turning left across LRT median transit lane violating NO LEFT TURN.
3- Motorists turning right in front of LRVs.

3.9 San Francisco, California

The San Francisco Municipal Railway (MUNI) operates five LRT lines. Most of the LRT system surface operation is in mixed traffic with few sections of separate right-of-way, Tunnel, median operations with curb, and transit lanes.

Market Street

On the at-grade section of the Market Street, tracks at several intersections have been moved from the inside lanes to the outside through lanes to provide exclusive left-turn lanes for automobiles. In the downtown area, the tracks occupy the inside lanes, with low station platforms between the inside lanes and the curb lanes.

Line J-Church

The 4-mile (6.4 km) J-Church line runs from the Doboce Avenue to Ocean Avenue. The entire line is double tracked where LRVs run at a speed between 20 and 30 mph (35 and 50 km/h) depending on the traffic condition. LRVs operate in mixed traffic except between 18th and 21st Street. It runs in a semi-exclusive right-of-way. LRVs also run in a median between Randall Street and the I-280 freeway. The headway for the LRVs is six minutes in the peak period and 12 minutes off-peak of a typical train consisting of one-car.

Line K-Ingleside

The entire 2.7 mile (4.3 km) length of the line is double tracked. LRVs operate in a nonexclusive right-of-way for about 0.6 miles (0.97 km) sharing the inside through lanes with road traffic and for 0.3 miles (0.48 km) in a semi-exclusive right-of-way along a median. In the 1.4 miles (2.2 km) segment between Junipero Serra Boulevard and Geneva Avenue, LRVs operate in the center of the roadway in mixed traffic. The rest 0.4 miles (0.64 km) from Geneva Avenue to Metro Center Yard, LRVs operate in the median in an exclusive transit lane right-of-way. LRVs operate in a two-car train consists all times except during the late evening hours it operates in one-car consists. At AM and PM peaks, LRVs operate at 10 minutes headway which increases to 12 minutes in the off-peak periods.

Line L-Taraval

This line is 3 miles (4.8 km) double tracked except for the turnabout loop segment at the end of the line. This LRT consists of two-car train consists operating at a speed of 25 mph (41 km/h) and six minutes headway during the peak hours. During the off-peak hours, the headway increases to 12 minutes. The LRVs run in the middle of the street and no station platform is provided. Thus, passengers have to cross the adjacent parallel traffic lanes to board and alight the LRVs.

Line M-Ocean View

Sharing a segment with Line K, the Line M continues to Metro Center Yard via San Jose Avenue. This line is a 4-mile (6.4 km) double tracked segment. The two-car LRV consist runs in a 2.5 miles (4 km) nonexclusive right-of-way, 0.5 miles (0.8 km) semi-exclusive right-of-way, and one mile (1.6 km) in a median fenced, semi-exclusive right-of-way. High station platforms are located in the median of the semi-exclusive portion, while in the nonexclusive portion no platforms are provided. The typical AM and afternoon headway is 20 minutes and 12 minutes during the PM peak.

Line N-Judah

It is a 4.5 mile (7.2 km) service from the Doboce Avenue to the Upper Great Highway. LRVs operate on the surface in mixed traffic, semi-exclusive, or nonexclusive rights-of-way. LRVs in shared rights-of-way are governed by standard traffic signals. LRT signals consist of two-head red and green "X" aspect. The red "X" requires the LRV operator to stop, while green "X" instructs the operator to proceed. In some locations an extra yellow "X" indication is installed requiring the operator to stop.

One of the main concerns in the San Francisco LRT system is left turning vehicles blocking the LRV tracks waiting for a gap to complete their turning movement. San Francisco has some problems with passengers queuing in the street in traffic lanes while waiting to board and alight an LRV, when no station platforms are provided. Disembarking passengers are also in a great risk as they step down of the LRVs. To overcome this problem MUNI installed median islands at stations where street geometry permits.

The highest accident percentages in MUNI are 25% where motorists turned left and right in front of the LRVs, 19% involved rear end collisions, 16% involved sideswipes, and 15% involved right angle collisions, while 2% involved pedestrians.

3.10 San Jose, California

The 19-mile (30.5 km), north-south LRT line operated by Santa Clara County Transportation Agency (SCCTA) links between Old Ironsides Station in Santa Clara and Santa Teresa Station in San Jose. The north end is a 6.7-mile (10.8 km) double track segment where an LRV operates in the median. Except for a short portion where LRV operates in a semi-exclusive alignment. The two-LRV consists run with 10-minute headways during the peak period, increasing to 15 minutes during the off-peak. The operating speed for the north-end segment is 35 mph (55 km/h) with crossing 1,100 feet (335.5 km) apart.

In the 2.2-mile (3.5 km), single track downtown loop segment, tracks are located in a transit/pedestrian mall right-of-way adjacent to the parallel roadway. In this portion, turns are restricted by active signs when an LRV is present. LRVs operate at 10 mph (15 km/h) where roadway crossings are 800 feet (244 km) apart.

The south-end is a 9.3 mile (15 km), double tracked segment running in the median of Carlo Street. It continues in the median of Guadalupe Expressway on an exclusive alignment with no grade crossings. The peak period headway is 10 minutes for the two-LRV consists, and changes to 15 minutes for the one-LRV consist during the off-peak at a maximum speed of 55 mph (90 km/h).

LRV in the shared right-of-way in San Jose is governed by a louvered, single section, “T” signal aspect installed on the fare side of the intersection. In the downtown transit/pedestrian mall a louvered, three section “T” aspect installed on the fare side of the intersection and unlouvered, three section “T” is installed on the near side of the intersection.

LRT signals located on the far side of the intersection are mounted on a post between the double set of tracks at the same height as the motor vehicle traffic signals. Internally illuminated NO RIGHT TURN signs are also installed in the downtown LRT/pedestrian mall to control right turns across the side aligned LRT tracks. Moreover, internally illuminated TROLLEY COMING signs are installed in the median to warn motorists who are making left turns in the presence of an approaching LRV.

Most frequent problems involve motorists turning left in front of overtaking LRVs, often against traffic signals. Actions taken by SCCTA toward this point and other problems were:

- The installations of active yellow, internally illuminated, TROLLEY COMING signs at all left-turn lanes to inform motorists of the increased risk of violating the red left-turn signal during the approach of LRVs.

- In some locations SCCTA installed pedestrian swing gates at crossings to reduce the number of collisions between pedestrians and LRVs.

- The originally installed three-colored “T” LRT signals on the far side of the intersection in the median were replaced by a single “T” with louvers. The function of the louver is to prevent motorists in the left-turn lane from seeing the LRT signals to minimize motorists' confusion.

- Additional RXR pavement markings at crossings were made. The original RXR pavement markings were found to have little or no effect on motorists.

Pedestrians receiving conflicting messages was one of the contributing accident factors in the pedestrian/transit mall accidents in San Jose, 84% involved motor vehicles turning in front of LRVs, 9% involved right-angle collisions, 5% involved pedestrians, and 1% other accidents.

3.11 Accident Types

LRT systems that operate LRVs in shared rights-of-way could experience problems relating to capacity, reliability of travel time, and safety. The nature and extent of these accidents depend on specific system features such as alignment choices, right-of-way design, and traffic control system.

The following section presents the common and the principal problems caused by LRVs operating in shared rights-of-way as a result of the survey of ten (10) LRT systems operating in shared rights-of-way (TCRP 17).

1. Pedestrians trespass on-side-aligned LRT tracks where no sidewalks are provided.
2. Pedestrians jaywalk across LRT rights-of-way.
3. In many instances, pedestrians do not have adequate, safe queuing areas.
4. Different LRT alignment designs confuse motorists and pedestrians and result in high accident frequencies.
5. Illegal left turns across LRT made by motorists account for most accidents.
6. Motorists' violation of red left-turn arrows.
7. Red time extensions resulting from multiple LRV preemption cause motorists waiting to turn left across the LRT tracks to become impatient.
8. Motorists' violation of LEFT RIGHT TURN signs, especially where left turns before the LRT system were constructed.
9. Motorists' confusion between LRT signals and general traffic signals.
10. Motorists' confusion between the indications of LRT signals and traffic signals.
11. Motorists drive on LRT rights-of-way that are delineated only by solid double yellow striping.
12. Motorists violate traffic signals at perpendicular grade crossings trying to beat LRVs to the crossing.
13. Complexity of intersection geometry complicates motorist and pedestrian decisions.

The accident experience of LRT systems in shared rights-of-way where LRVs operate less than 35 mph is summarized in **Table 3.2.** The average number of accidents occurring in separated or shared rights-of-way per year was 47.5. Of the 47.5 accidents, 92% occurred in rights-of-way at or less than 35 mph. Individual cities experienced no less than 70% accidents in shared rights-of-way at or under 35 mph. The average safety index for all systems was 3.7, while individual city indexes ranged from 0.5 to 6.2.

Traffic control systems at LRT systems in shared rights-of-way less than 35 mph are shown in **Table 3.3**. Street median and side-running alignments are most commonly used by LRT systems. Fifty percent of the LRT systems use standard traffic signals while the other 50% use other devices such as the monochrome bar and T, and the colored T and X signals. Of the ten LRT systems surveyed, 40% have partial traffic signal priority/preemptions in place, 30% have proposed or are in the testing process, and 20% (Calgary and San Diego) have no signal progressive mechanisms. As shown in **Table 3.2**, the systems with no signal progression (Calgary and San Diego) have the lowest percentage of accidents.

Table 3.2 - Accident Experience in Shared Rights-of-Way Where LRVs Operated at or under 35 mph

LRT System	Average Number of Accidents/year in Separate or Shared R/W	Average Annual Number of Accidents in Shared R/W at or under 35 mph	% of Accidents in Shared R/W at or under 35 mph	Total Mainline Track Miles	Mainline Track Miles Shared R/W at or under 35 mph	% of Mainline Track Miles in Shared R/W at or under 35 mph	Safety Index for Shared R/W at or under 35 mph (Average Number of Accidents/track Mile/year)
Baltimore	27.8	24.8	89%	23.9	4.2	18%	5.9
Boston	97.0	97.0	100%	49.4	15.6	32%	6.2
Buffalo	1.1	1.1	100%	11.8	2.4	20%	0.5
Calgary	22.4	15.9	71%	35.2	2.6	7%	6.1
Los Angeles	58.3	46.1	79%	42.6	10.0	23%	4.6
Portland	23.0	20.7	90%	27.1	14.0	52%	1.5
Sacramento	27.0	23.0	85%	35.2	9.2	26%	2.5
San Diego	27.1	20.3	75%	66.0	7.0	11%	2.9
San Francisco	165.3	165.3	100%	52.6	37.0	70%	4.5
San Jose	25.5	25.0	98%	35.4	15.4	44%	1.6
All Systems	47.5	43.9	92%	379.2	117.4	31%	3.7

Source: Korve Engineering research team interview/survey at the 10 LRT systems, Summer 1994.

Table 3.3 - Traffic Control Systems at LRT Systems Surveyed (Shared Rights-of-Way under 35 mph)

ITEM	SYSTEM									
	Baltimore	**Boston**	**Buffalo**	**Calgary**	**Los Angeles**	**Portland**	**Sacramento**	**San Diego**	**San Francisco**	**San Jose**
Alignment Types										
- Street Median	X	X			X	X	X	X	X	X
- Side-Running	X	X	X		X	X	X	X		
- Mixed Traffic		X				X	X		X	
- Ped/Transit Mall			X	X			X	X		X
LRT Signal Aspect	Monochro-me bar	Standard traffic signal	Standard traffic signal	Standard traffic signal Station clearance interval signal	Colored T	Monochro-me bar	Monochro-me T	Standard traffic signal Green T Yellow ball	Standard traffic signal Colored X	Colored T
Traffic Signal Priority/ Preemption	Proposed	Testing	Partial	No (Signal Progression)	Partial	Yes	Partial	No (Signal Pro-gression)	Proposed	Partial
Active Internally Illuminated Sign (on left turn, no right turn, second train coming)	Yes	No	No	No	Yes	Yes	Yes	Yes	No	Yes
Dynamic Envelop Delineation	Howard Street	No	6 inch raised curb	Yellow paint line (7th Avenue Mall)	No	Granite	Traffic lane striping at pedestrian mall	Double yellow line	At some turns dashed or solid line, raised tracks on Judah Street	At pedestr-ian mall
Special Pedestrian Crossing Controls	No	No (some fencing)	No	Bedstead barriers Swing gates	Proposed	Z-crossings	No	No	Z-crossings (South Embarcadero, 19th Avenue)	No

Source: Korve Engineering research team interview/survey at the 10 LRT systems, Summer 1994.

4 CASE STUDY - SOUTH DADE BUSWAY, MIAMI, FLORIDA

4.1 Previous Experiences

The South Dade Busway project was not the first experience of bus priority treatments in Dade County. In July 1974, the South Dixie Highway Blue Dash system started operation to serve commuters in the South Miami Corridor (OECD 1977). The system extended for approximately six miles on US 1 (South Dixie Highway), a six-lane divided roadway, with 17 major signalized intersections. During the peak periods, two lanes are reserved for general traffic, the median with-flow lanes are reserved for HOV and carpooling, while buses operate in a contra-flow lane taking over the median as shown in **Figure 4.1**. Signal progression along the corridor was set at 35 to 40 mph and left turns were prohibited during the peak hours. Although the general traffic lanes suffered from a one minute delay, and the number of accidents increased from 148 to 245 in a nine month period, buses saved nine minutes and HOV's saved six minutes in trip time, respectively. Due to the high enforcement and operating costs of the contra-flow lane, buses were moved to the HOV lane for an experimental period of six months.

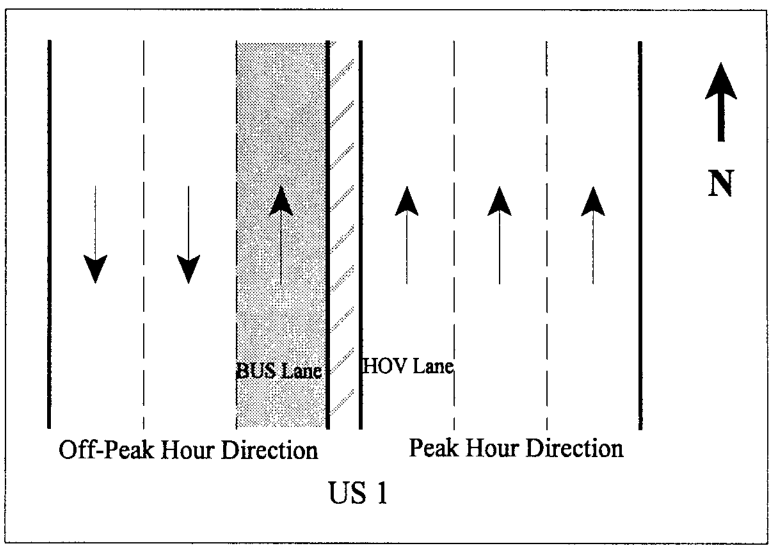


Figure 4.1 - South Dixie Highway Blue Dash System

The second bus priority treatment in Dade County was a research project, as it was planned to be the first stage for the North Miami Corridor (NW 7th Avenue). The NW 7th Avenue system served three major employment centers in Miami and the northern suburbs. The system consisted of 10 miles (16.1 km) and 37 intersections in the center reversible reserved lanes of the NW 7th Avenue. Intersections were equipped to detect the light signal emitted by the buses. The northern terminal of the system was a major parking facility. Although the project resulted in a 34 percent increase in ridership, illegal left turns were the major cause of accidents.

4.2 South Dade Busway, 1997 Experience

4.2.1 Introduction

In February of 1997, the Florida Department of Transportation (FDOT) and Metro Dade Transit Agency (MDTA) started the operation of the third bus priority treatment in Dade County history. The South Dade Busway is an exclusive at-grade busway and the first of its kind to be implemented in North America. The at-grade busway was built to ease traffic congestion along the heavily congested US 1 corridor between Dadeland South Metrorail Station and Cutler Ridge Mall. In addition to improving bus travel speeds, other amenities are incorporated into the busway to encourage transit use.

US 1 is the most important surface arterial south of the Miami CBD, carrying volumes ranging from 50,000 to 90,000 AADT in 1993. US 1 is the main corridor connecting Homestead and Florida City to South Miami and Miami CBD. The bus service on the Busway provides another alternative to cars having the same reliability, speed and comfort but less expensive. Traffic congestion and delays are expected to be relived by the operation of the new bus services on the busway. Residents of South Dade can ride the busway and then transfer to the Metrorail at Dadeland South Station, where the busway ends and Metrorail begins, to go to Downtown Miami or other major activities in Dade County. The alignment of the busway, Metrorail, and major highways, and the location of some major activity centers in Dade County are shown in **Figure 4.2**. The 8.2-mile segment of the corridor between Dadeland South Metrorail Station and the Cutler Ridge Mall has a combination of commercial, residential, and recreational areas, and schools. Three of the major shopping centers in Miami are located along the busway (Dadeland Mall, The Falls, and Cutler Ridge Mall). Some of the major activity generators along the busway corridor such as the location of park-and-ride lots, shopping centers, hospitals, universities, fire stations, and major streets are shown in **Figure 4.3**. Currently, the Dadeland Mall has the highest employment density along the corridor, but in the year 2000 the Falls will experience an increase in employment density due to new expansions. Other major activity centers such as automobile dealerships, hospitals, and shopping plazas are also located along the corridor. Most of the commercial activities along the corridor are expected to see an increase in their employment densities by 25 to 40 percent. Due to this increase in employment densities, residential density is also expected to increase in areas adjacent to the corridor, which is expected to take place in areas west of the corridor between SW 152nd Street and SW 200th Street. The population and employment densities by traffic analysis zones (TAZs) along the busway for 1993 and the forecasted densities for the year 2000 are shown in **Figures 4.4, 4.5, 4.6,** and **4.7**, respectively. The traffic congestion and delays due to the increase in population and employment density is expected to ease by the busway as well as attracting new riders.

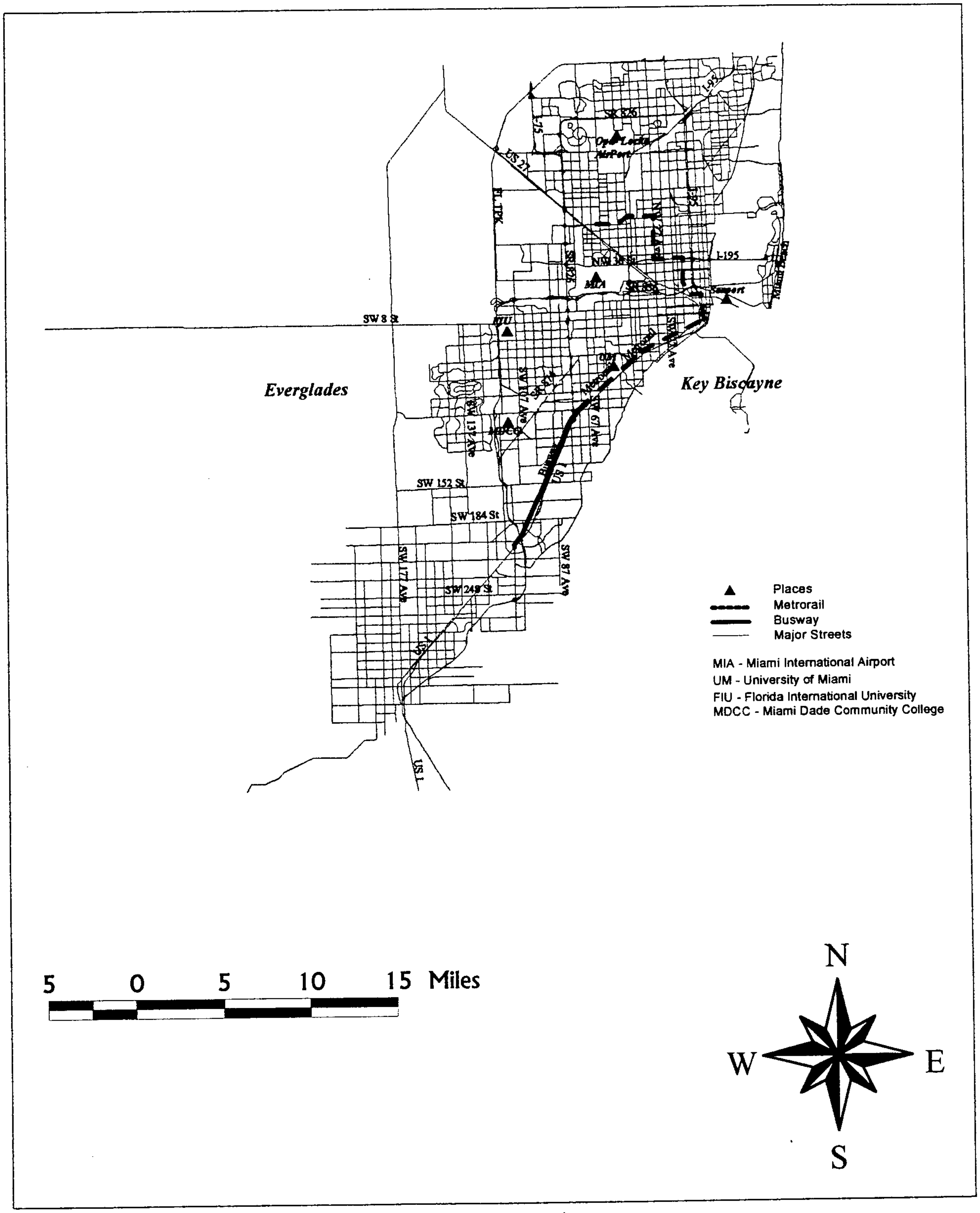


Figure 4.2 - Major Activity Centers in Dade County

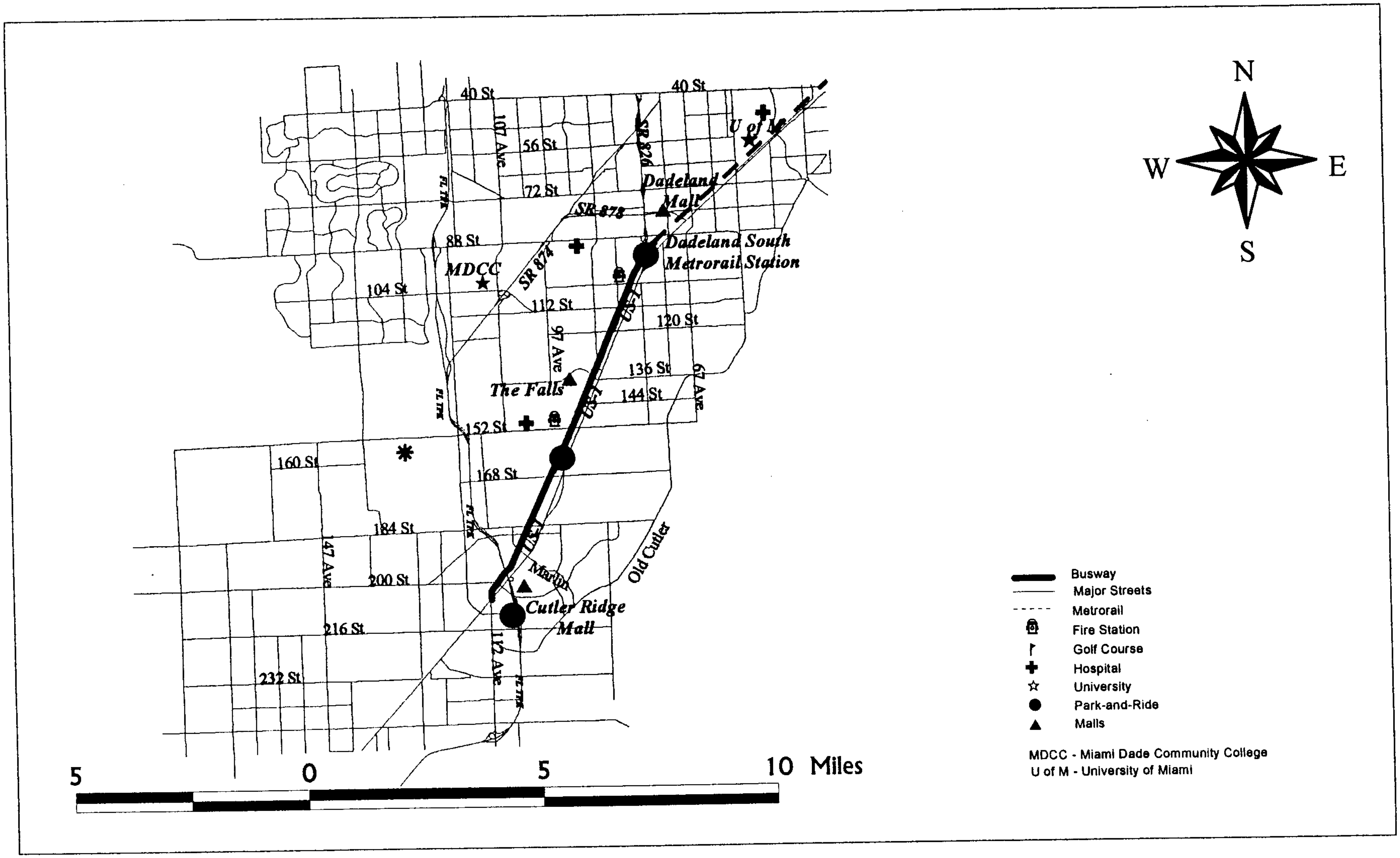


Figure 4.3 - Major Activities along South Dade Busway

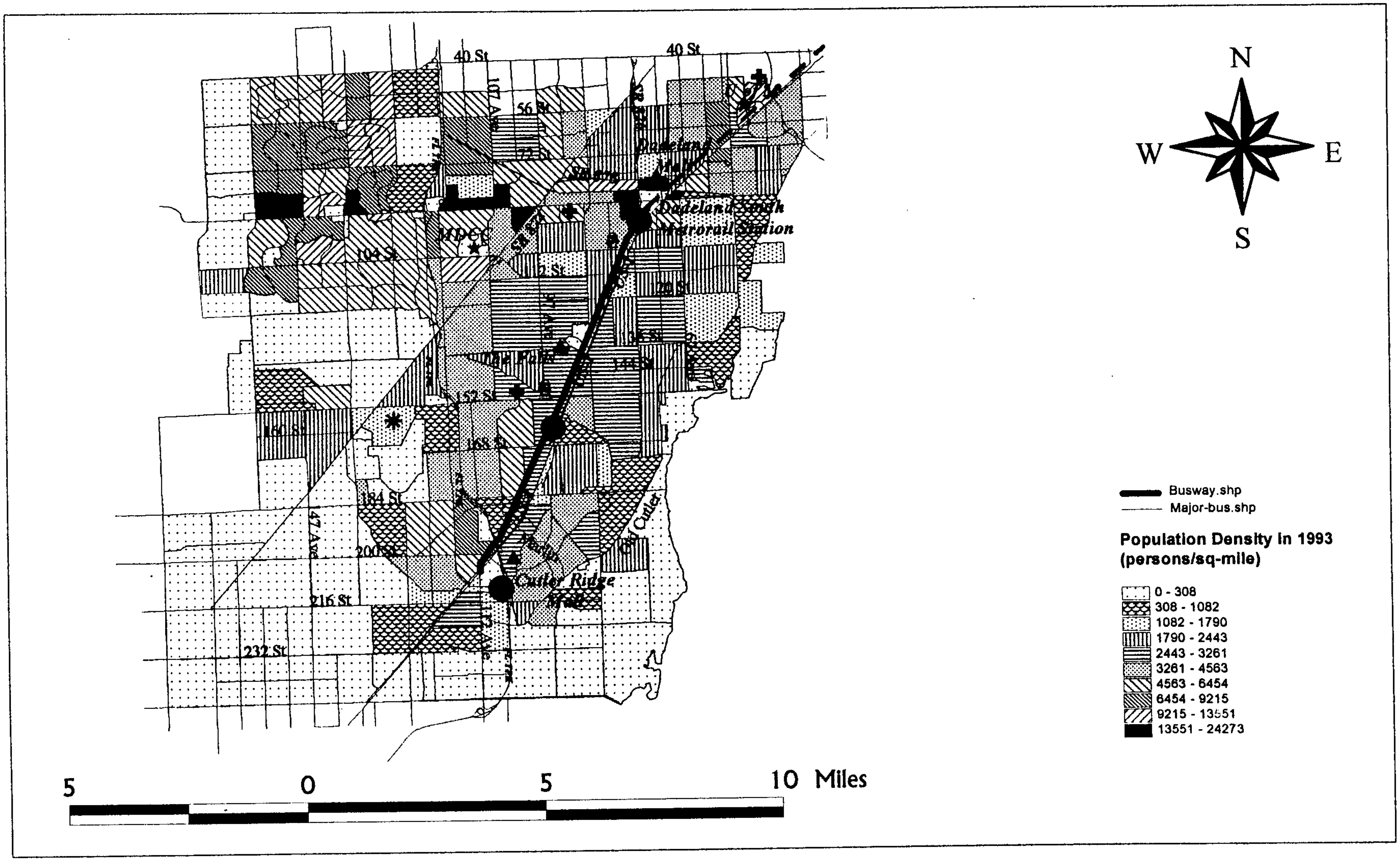


Figure 4.4 - Population Density along the Busway as of 1993

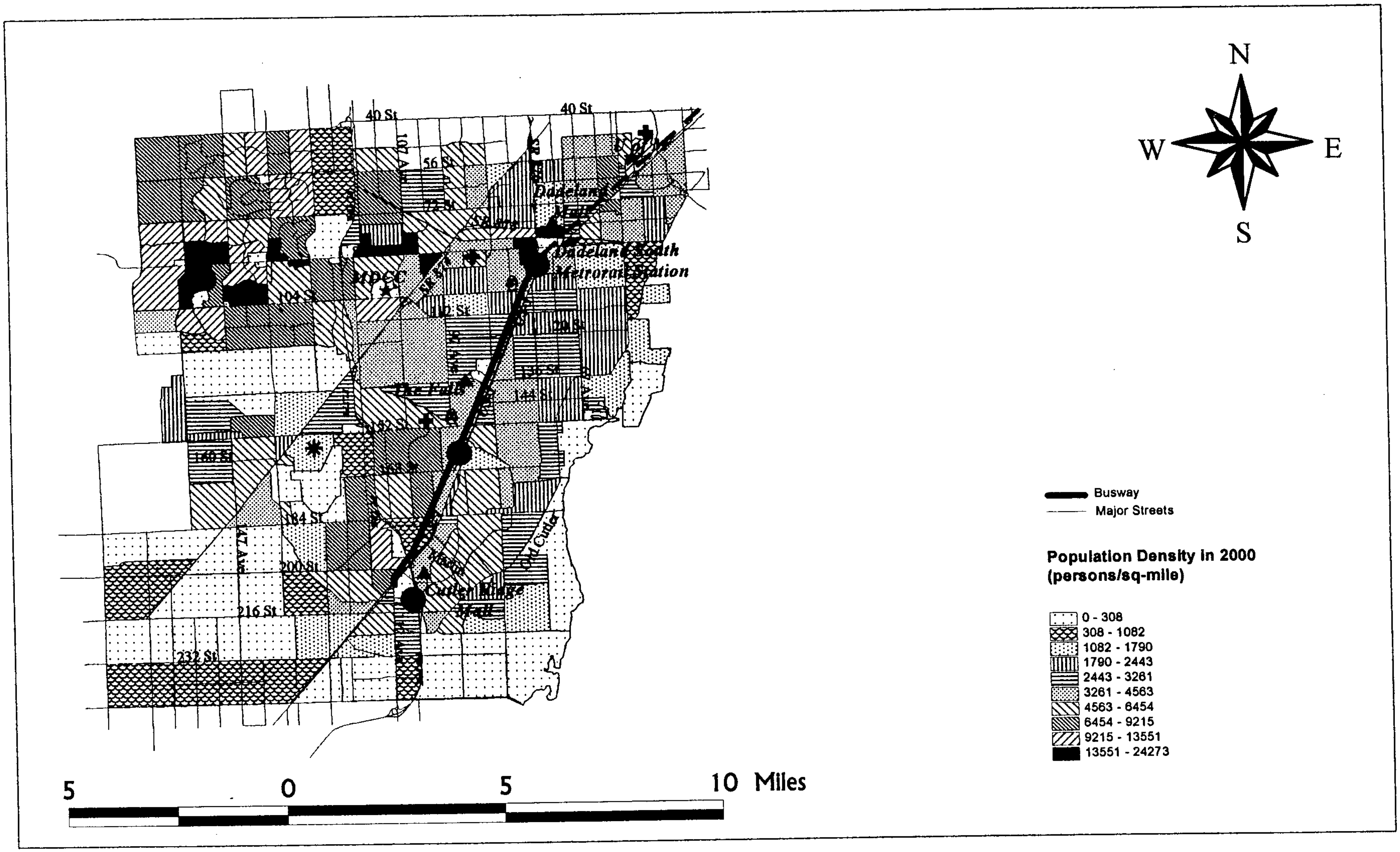


Figure 4.5 - Population Density along the Busway as of 2000

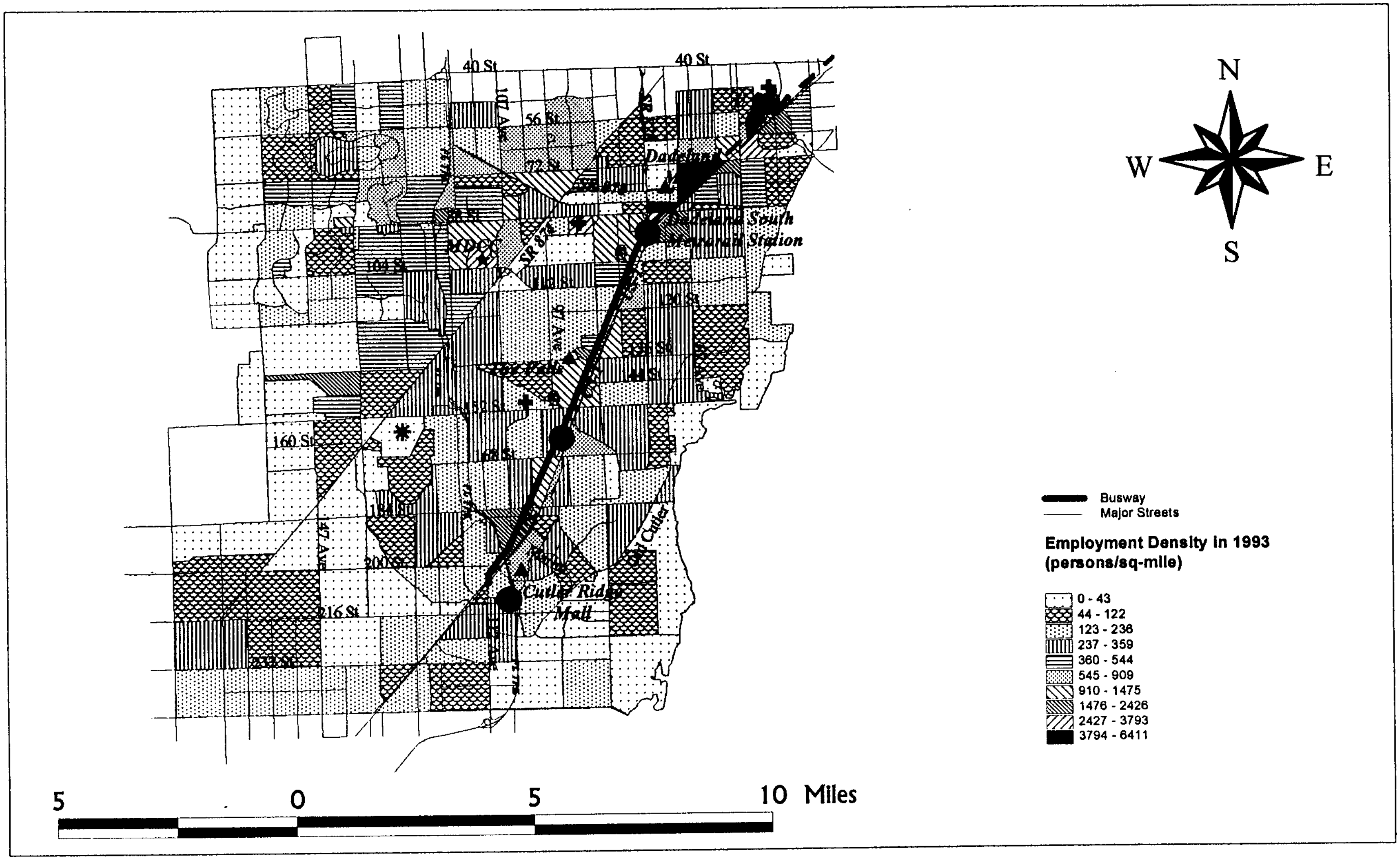


Figure 4.6 - Employment Density along the Busway as of 1993

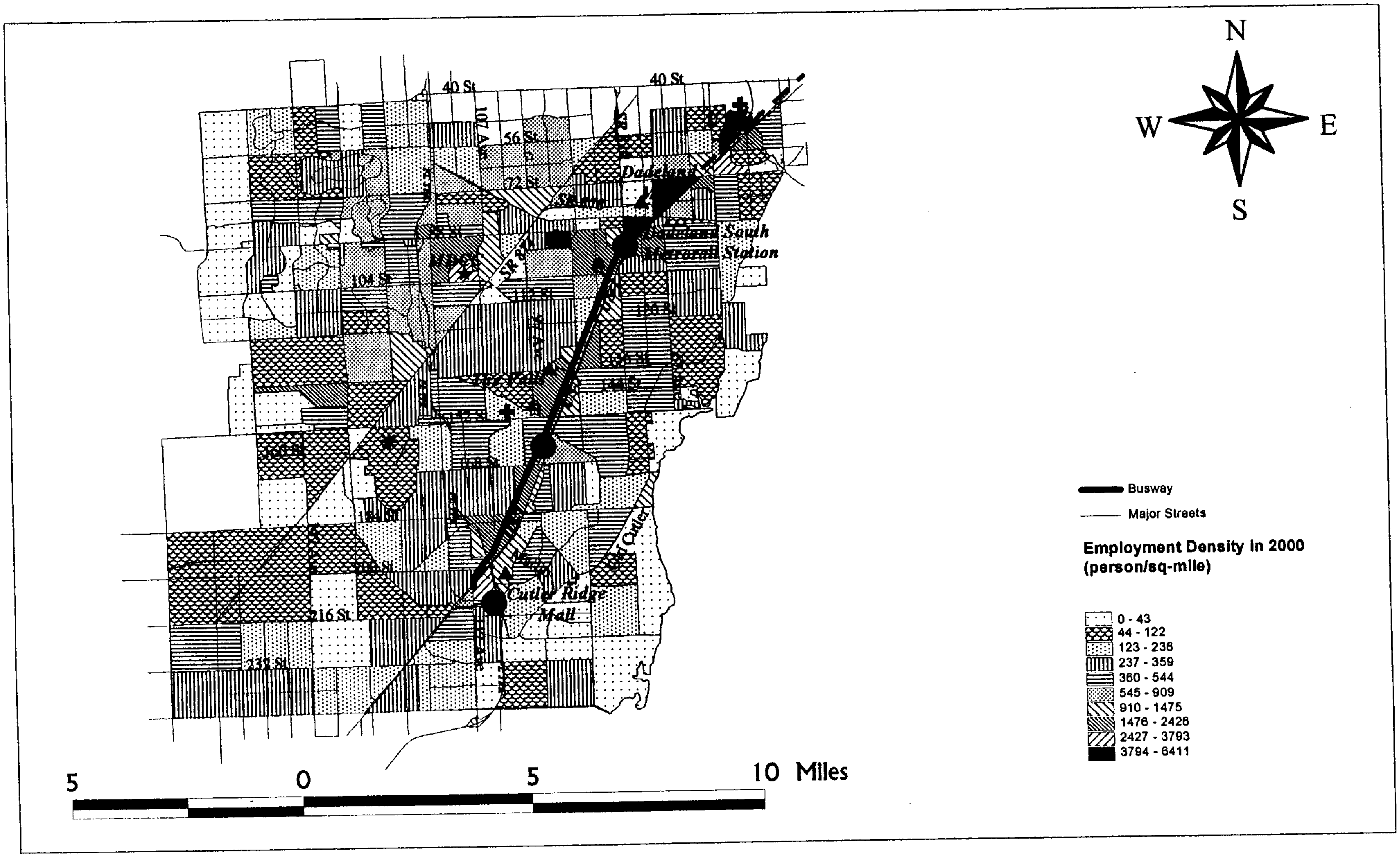


Figure 4.7 - Employment Density along the Busway as of 2000

4.2.2 System Description

South Dade Busway is an 8.2-mile, separate, at-grade roadway for the exclusive use of buses and emergency vehicles as shown in **Figure 4.8**. The busway was built in an abandoned railroad right-of-way located to the west of US 1, as illustrated in **Figure 4.9**, at a cost of $21 million. The

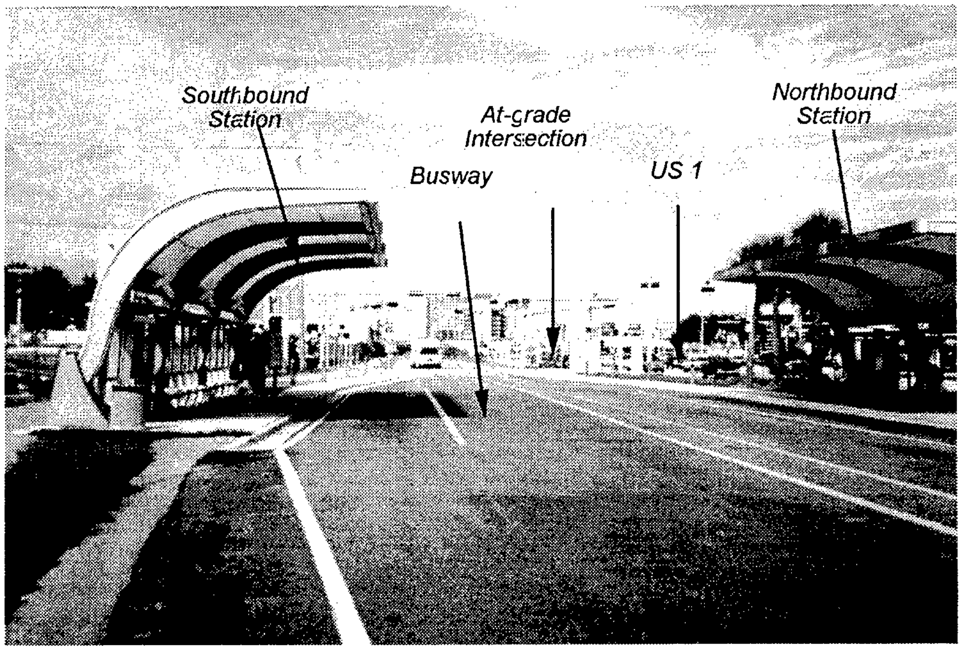


Figure 4.8 - South Dade Busway

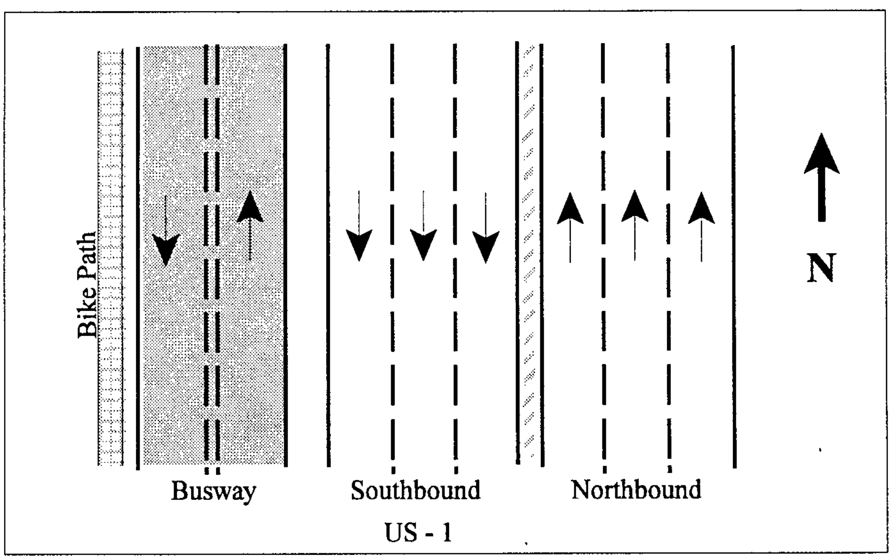


Figure 4.9 - South Dade Busway Configuration

construction costs include the costs of stations, signing, traffic control signals, landscaping, park-and-ride lots, and the bike path. Buses operate on two exclusive at-grade 12-foot lanes with a 4-foot buffer in between. At station areas, the width of the busway increases from 28 feet to 52 feet to allow express buses to bypass other local buses alighting and boarding passengers at the stations.

The busway intersects with 20 major signalized intersections, of which 11 are within a 50 to 80 feet separation distance between the busway and the pavement edge of US 1. At these intersections, the busway and US 1 operate as a single signalized intersection (combined intersection). In order to operate the busway safely, exclusive right turn lanes with right turn signals along the US 1 southbound were added at most of the intersections to provide an exclusive right turn movement as shown in **Figure 4.10**. Another safety measure was the conversion of northbound left turns to restrictive protection phasing. The close separation distance between the busway and the US 1 edge of pavements and the installation of a portable message sign during the early periods of operation with NO TURN ON RED indication to warn the motorists with the new signal configurations and the operation of the busway is also shown in **Figure 4.10**. Side street operations were also converted to directionally separated phasing. Programmable signal heads were installed at the side streets to prevent the motorists confusion between busway and US 1 signal heads.

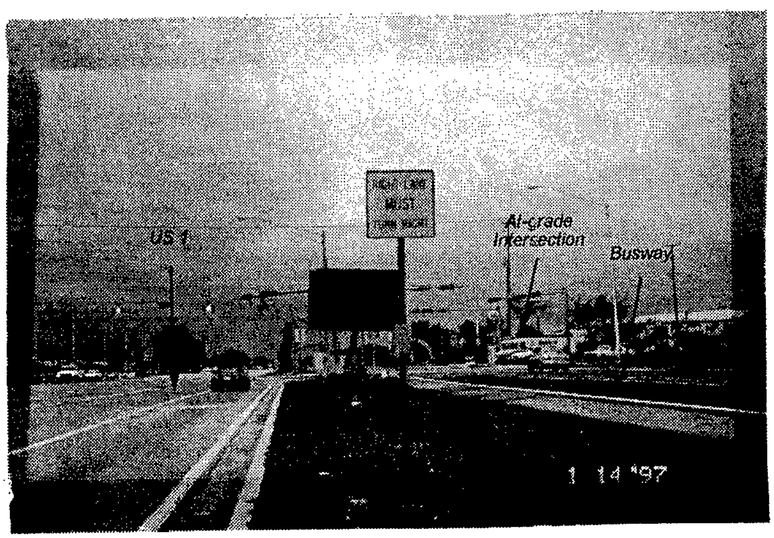


Figure 4.10 - New Exclusive Right Turn along US 1

A 10-foot bicycle path is also provided west of the busway. In addition of providing for the north-south movement of non-motorized traffic, the South Dade Trail collects and distributes pedestrians and bicyclists to and from the busway stations. An example of signs on the bike path to inform cyclists of major activities that are accessible by bicycles is shown in **Figure 4.11**. Pedestrian signal are also installed to control movements of non-motorized traffic across the streets that intersect with the Busway.

Figure 4.11 - Bike Path Information at SW 112 Street

Advanced vehicle motion detectors are installed on the at-grade busway to allow express buses to travel from Dadeland South Station to Cutler Ridge Station without stopping. The advanced vehicle detectors shown in **Figure 4.12** are placed at 600 feet and 375 feet before the intersection to allow an approaching bus, if arriving during the allowable preemption window, to proceed through the intersection without stopping (Fowler 1995). Sufficient time is given for the preemption phase to terminate and clear before a bus reaches the dilemma zone. Thus express buses can travel the entire length of the at-grade busway without making a local stop.

Figure 4.12 - Advanced Vehicle Detectors Installed on the Busway

Along the busway, there are 17 stations in each direction. Each station is equipped with a bus bay that accommodates two full size buses. The innovative design of the shelter at stations, shown in **Figure 4.8**, protects the passengers from the adverse weather changes in South Florida while waiting, alighting, or boarding a bus. Three park-and-ride lots are also provided along the at-grade busway at Dadeland South Metrorail station, SW 152nd Street, and Cutler Ridge Mall. Both park-and-ride lots at SW 152nd Street Station and Cutler Ridge Mall are free of charge. Dadeland South Station serves as an intermodal transportation center. It is equipped with a multistory garage, where passengers can park their cars and either ride local bus routes, busway route, or the Metrorail. Passengers can also transfer from local or busway routes to the Metrorail to complete their trips. Another surface parking lot is located across a side street from Dadeland South Station. The station is also connected to the Datran Business Center and Dadeland Marriot Hotel. A view of the at-grade busway station at the lower level and the Metrorail at the upper level of the Dadeland South Station is shown in **Figure 4.13**.

Several new local and express bus routes serve areas east, west, and south of the busway. Transit services presently serving the busway station are shown in **Table 4.1**. New local and express buses with limited or non-stop services, shown in **Figure 4.14**, are added to link the adjacent residential and commercial areas along the busway with other major activity centers in Dade County. During peak periods the headway between vehicles serving the busway is five minutes.

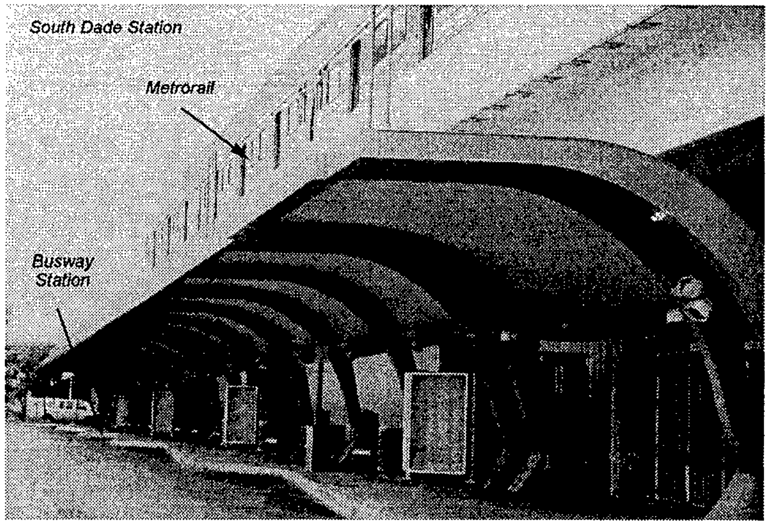


Figure 4.13 - Dadeland South Station

Table 4.1 - Different Routes Serving the Busway Stations

Station / Stop	Routes Serving the Stations
C. Ridge Park & Ride	Busway MAX/Local, 35, 52, 70
SW 200 St	Busway MAX/Local, 1-Busway, 1-US 1
Marlin Dr	Busway MAX/Local
SW 184 St	Busway MAX/Local, 35
W Indigo St	Busway MAX/Local
SW 173 St	Busway MAX/Local, 52
SW 168 St	Busway MAX/Local, Saga Bay MAX, 1-Busway
SW 160 St	Busway MAX/Local, Saga Bay MAX, 1-Busway
SW 152 St	Busway MAX/Local, Saga Bay MAX, 1-Busway, 57
SW 144 St	Busway MAX*/Local, Saga Bay MAX, Coral Reef MAX, 1-Busway, 52
SW 136 St	Busway MAX*/Local, Saga Bay MAX, Coral Reef MAX, 1-Busway, 52, 65
SW 128 St	Busway MAX*/Local, Saga Bay MAX, Coral Reef MAX, 1-Busway, 52
SW 124 St	Busway MAX*/Local, Saga Bay MAX, Coral Reef MAX, 1-Busway, 52
SW 117 St	Busway MAX*/Local, Saga Bay MAX, Coral Reef MAX, 1-Busway, 52
SW 112 St	Busway MAX*/Local, Saga Bay MAX, Coral Reef MAX, 1-Busway, 52
SW 104 St	Busway MAX*/Local, Saga Bay MAX, Coral Reef MAX, 1-Busway, 52
Dadeland South	Busway MAX*/Local, Saga Bay MAX, Coral Reef MAX, 1-Busway, 52, 73

*Stops only during off-peak hours and weekends.

After the busway started operation in February 1997, most bus routes operating along US 1 shown in **Figure 4.14** experienced a decreased in ridership, while the total average weekday boarding of February 1996 and 1997 increased by 12.5%. This is shown in **Table 4.2**. Through the end of February 1997, the average weekday boardings on the busway routes were 10,066, an increase of 21%. At the end of March 1997, the ridership levels indicated an increase of 39.1% in the total monthly ridership, shown in **Table 4.3**. This increase in the ridership for routes operating on the busway positively impacted the Metrorail ridership. The average weekday boardings at Dadeland South and Dadeland North Metrorail Station increased by 2%, while the combined bus and rail average weekday and weekend boardings increased by 17% and 18%, respectively. The busiest busway stations are Dadeland South Metrorail Station, SW 200 Street Terminal Station near Cutler Ridge Mall, and SW 152 [nd] Street Station due to the existence of park-and-ride lots.

Table 4.2 - Metrobus Boardings by Route (February 1996-February 1997)

Routes	Avg. Weekday Boardings			Tot. Monthly Boardings		
	1996	1997	% Change	1996	1997	% Change
1	2,724	1,556	*(42.9)%*	64,462	36,962	*(42.7)%*
35/70	2,196	1,949	*(11.2)%*	45,804	38,405	*(16.2)%*
52	1,785	1,097	*(38.5)%*	36,995	21,986	*(40.6)%*
57/72	1,249	1,872	*49.9%*	25,999	36,994	*42.3%*
73	2,431	2,504	*3.0%*	56,220	54,478	*(3.1)%*
65EX	-	117	-	-	2,340	-
Busway Local [a]	-	436	-	-	5,780	-
Busway Max [a]	-	1,098	-	-	13,756	-
Coral Reef [a]	-	648	-	-	7,166	-
Saga Bay [a]	-	406	-	-	4,101	-

Source: MDTA Ridership Technical Report.

[a] New bus routes along the busway.

(%) Percentage decrease.

Table 4.3 - Metrobus Boardings By Routes Along Busway (February and March 1997)

Routes	Average Weekday Boarding			Total Monthly Boarding		
	FEB	MAR	% Change	FEB	MAR	% Change
1	1,556	2,070	*33.0%*	36,962	50,492	*36.6%*
35/70	1,949	1,890	*(3.0)%*	38,405	39,696	*3.4%*
52	1,097	1,451	*32.3%*	21,986	30,462	*38.6%*
57/72	1,872	1,808	*(3.4)%*	36,994	37,958	*2.6%*
73	2,504	2,395	*(4.4)%*	54,478	56,626	*3.9%*
65EX	117	123	*5.1%*	2,340	2,589	*10.6%*
Busway Local	436	661	*51.6%*	5,780	21,971	*280.1%*
Busway Max	1,098	1,299	*18.3%*	13,756	40,482	*194.3%*
Coral Reef	648	680	*4.9%*	7,166	18,033	*151.6%*
Saga Bay	406	501	*23.4%*	4,101	10,513	*156.4%*
TOTAL	11,683	12,878	*10.2%*	221,968	308,822	*39.1%*

Source: MDTA Ridership Technical Report.

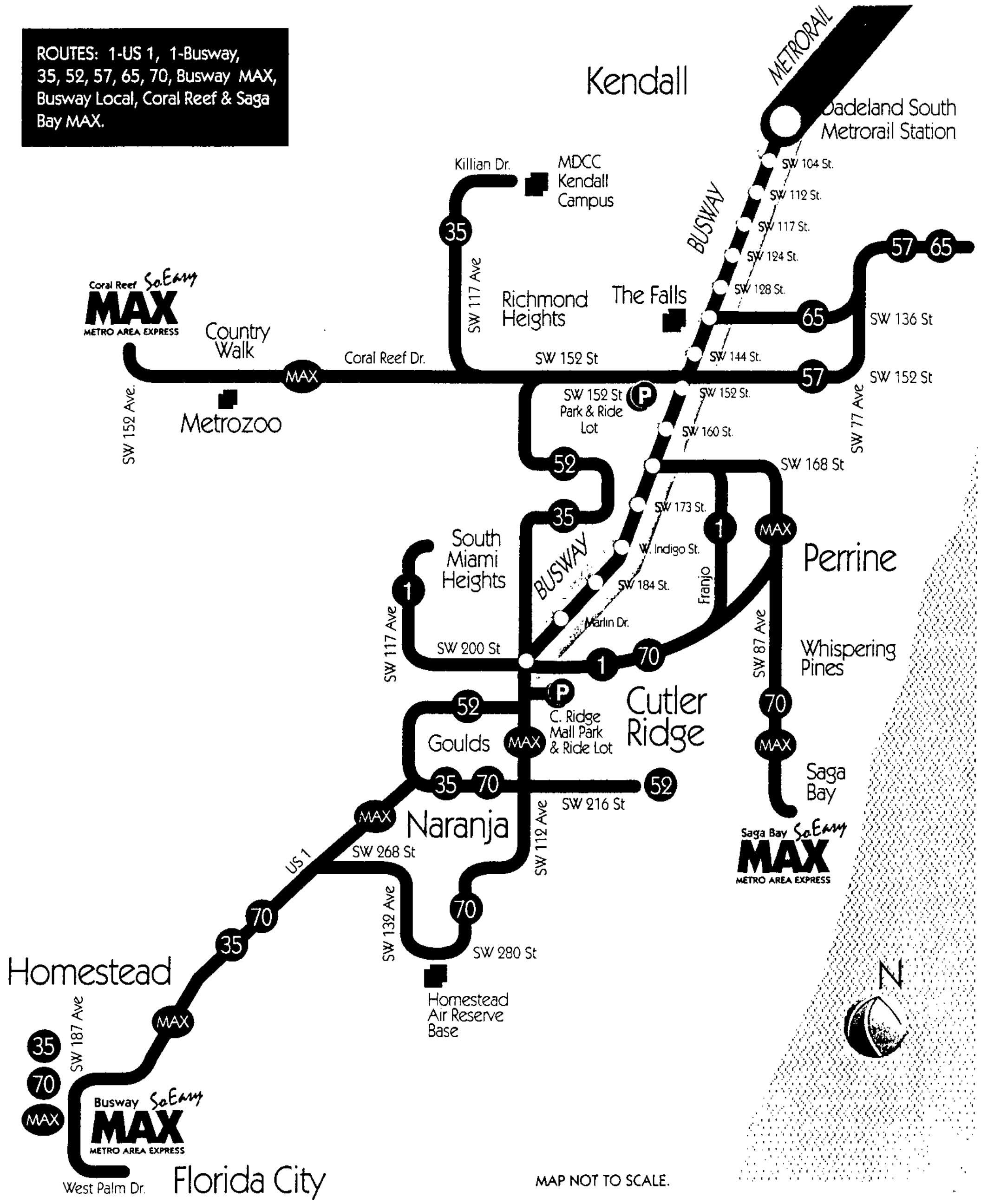


Figure 4.14 - South Dade Transit Service

4.2.3 TRAFFIC DATA COLLECTION

As the South Dade busway was the first at-grade busway system to be implemented in the U.S., its effect on traffic on adjacent and cross streets was not known. Thus data collection was performed before and after the busway began its service. Before the busway began operation, detailed traffic data were collected at each of the 20 crossings along the busway. Updated condition diagrams of the intersections were used to evaluate the geometric configuration of each crossing. Based on the evaluation of the collected data, six intersections were selected for detailed traffic studies. After the busway started operation, traffic studies were performed, but additional intersections were selected due to the heavy delays resulted from the operation of the busway.

4.2.3.1 BEFORE THE BUSWAY OPERATION

US 1 corridor in Dade County is a six-lane, highly congested highway. The northbound average annual daily traffic (AADT) was found to be 22,000 vehicle at the beginning of the busway at Cutler Ridge and building up to 44,000 vehicles at the end of the busway at Dadeland South Metrorail Station. At the same time, the AADT for the southbound was found to be 20,000 and 45,000 at Cutler Ridge and Dadeland South, respectively, as shown in **Table 4.4**.

Table 4.4 - Average Annual Daily Traffic along US 1

INTERSECTION	LOCATION	NORTHBOUND	SOUTHBOUND
US 1/SW 112 AVE	South	22,000	20,000
US 1/SW 152 ST	South	31,500	30,000
	North	36,500	44,000
US 1/SW 112 ST	South	37,500	39,500
US 1/SW 98 ST	South	44,000	45,000

Source: FDOT (Statistics Department).

Among the 20 signalized intersections along the busway, 11 intersections occur within a 50 to 80 feet separation distance between the busway and the US 1 edge of pavement. The distance between the busway and US 1 for the remaining intersections ranges from 250 to 400 feet. Six intersections were chosen for the pre-operation traffic data collection. These intersections were chosen among the 11 intersections that have a 50 to 80 feet separation distance between the busway and US 1.

Below is a list the intersections selected, as identified by the cross street, and reasons for which they are chosen:

- SW 104 St., SW 136 St., SW 160 St., and SW 112 Ave. - showed high traffic volumes generated by residential and/or commercial areas.

- SW 152 St. - a major traffic generator from new residential and commercial developments in the west and is the first street that connects to the Turnpike south of SW 104 St.

- SW 200 St. - presented a high volume of accidents.

The following studies were performed for the six intersections:

Intersection Traffic Volume Studies (turning movement counts): Intersection counts are taken to determine vehicle classifications though movements and turning movements at intersections. These data are used mainly in determining phase lengths and cycle times for signalized intersections, in the design of channelization at intersections, and in the general design improvements to intersections. Turning movement counts were collected manually in fifteen (15) minute intervals at all six intersections. The purpose of this study was to determine the maximum number of vehicles that pass through each intersection during a period of 120 consecutive minutes. The study hours were during the AM peak from 7:00 a.m. to 9:00 a.m. and during the PM peak from 4:00 p.m. to 6:00 p.m. A summary of the AM and PM turning movement counts for the six intersections before the operation of the busway is shown in **Tables 4.5** and **4.6**, respectively. These tables also show the peak hour and the total peak hour volume for each of the six intersections.

Intersection Delays: Delay is the time lost to travel because of traffic friction and traffic control devices. Delay data is mainly used to identify location with relatively high delays and the cause for those delays and to determine the efficiency of an intersection with respect to its ability to carry traffic. The field delay study before the busway operation was useful to estimate the portion of vehicles that were required to stop during the time periods when delays were measured. The delay study before the busway operation was performed at three intersections (SW 104 St., SW 136 St., and SW 152 St.). These three intersections were chosen for the delay study due to their high vehicular volume during the peak periods. The approach volume, and number of stopped vehicles at the three intersections selected for the delay study before the operation of the busway are shown in **Table 4.7**.

Spot Speed: The quality of travel is often associated with speed or travel time. Speed is an important consideration in highway transportation because the rate of vehicle movement has significant economic, safety, time, and service impact on both motorists and the general public. Spot speed is the instantaneous measure of speed at a specific location on a roadway. A sample size of 100 vehicles at each location was found to be suitable for the pre-operation data collection. The sample size was calculated based on a confidence level of 95.5% and a permitted error of ±1 mph. The average mean speeds for the AM northbound and PM southbound peaks at mid blocks between the major intersections are 40 and 43 mph, respectively. The mean speeds for segments between the six intersections are shown in **Table 4.8**. The average speeds are close to the posted speed limit along US 1 which is 45 mph.

Table 4.5 - Summary of the AM Peak Turning Movement Counts for Selected Intersections along US 1 Before the Operation of the Busway

INTERSECTION	PEAK HOUR	NORTHBOUND			SOUTHBOUND			EASTBOUND			WESTBOUND			PEAK HOUR VOLUME
		LF	TH	RT	LF	TH	RT	LF	TH	RT	LF	TH	RT	
SW 104 St.	7:45	106	2,765	12	226	1,829	101	290	154	32	38	176	265	5,994
SW 136 St.	8:00	179	2,716	81	57	1,251	331	207	207	165	127	178	54	5,553
SW 152 St.	8:00	293	2,385	96	144	728	448	591	266	183	154	306	62	5,656
SW 160 St.	8:00	89	2,222	16	62	1,048	122	322	66	115	13	59	32	4,166
SW 200 St.	7:45	96	2,043	26	117	853	152	422	223	62	229	296	204	4,723
SW 112 Ave	7:15	N/A	1,511	0	176	767	N/A	N/A	N/A	N/A	6	N/A	225	2,685

Note: SW 112th Street is a "T" intersection

Table 4.6 - Summary of the PM Peak Turning Movement Counts for Selected Intersections along US 1 Before the Operation of the Busway

INTERSECTION	PEAK HOUR	NORTHBOUND			SOUTHBOUND			EASTBOUND			WESTBOUND			PEAK HOUR VOLUME
		LF	TH	RT	LF	TH	RT	LF	TH	RT	LF	TH	RT	
SW 104 St.	4:45	171	2,122	16	345	3,147	287	186	201	111	68	159	89	6,902
SW 136 St.	4:45	220	1,520	107	154	2,958	319	265	241	147	256	302	68	6,557
SW 152 St.	4:30	238	1,591	126	181	2,671	363	300	282	303	272	314	56	6,697
SW 160 St.	4:45	171	1,650	25	79	2,497	305	243	103	152	26	65	32	5,348
SW 200 St.	5:00	144	1,434	76	287	1,596	349	274	247	97	329	342	365	5,540
SW 112 Ave	5:00	N/A	1,297	20	347	1,514	N/A	N/A	N/A	N/A	21	N/A	256	3,455

Note: SW 112th Street is a "T" intersection

Table 4.7 - Intersection Delay Study Before the Busway Operation

Intersection	Direction	Time	Approach Volume	Stopped Vehicles	Percent of Vehicles Stopped
SW 104 St.	East	7:00 - 7:30	214	203	94.85%
	West	7:30 - 8:00	25	19	76.00%
	East	4:00 - 4:30	107	100	93.46%
	West	4:30 - 5:00	30	28	93.33%
SW 136 St.	East	8:15 - 8:45	140	135	96.42%
	West	8:45 - 9:15	82	82	100.00%
	East	5:15 - 5:45	103	101	98.05%
	West	5:45 - 6:16	116	116	100.00%
SW 152 St.	East	N/A	N/A	N/A	N/A
	West	N/A	N/A	N/A	N/A
	East	4:00 - 4:30	188	180	95.74%
	West	4:30 - 5:00	181	181	100.00%

Table 4.8 - Average Speed at Selected Locations along South Dade Busway

INTERSECTION	BOUND	TIME	MEAN SPEED
SW 98 St.	Northbound	6:40 AM	43
SW 104 St.	Northbound	7:00 AM	37
SW 109 St.	Northbound	7:23 AM	29
SW 123 St.	Northbound	7:55 AM	41
SW 139 St.	Northbound	8:15 AM	42
SW 161 St.	Northbound	8:40 AM	43
SW 195 St.	Northbound	9:10 AM	46
Average Mean AM Speed			***40***
SW 104 St.	Southbound	4:00 PM	41
SW 139 St.	Southbound	4:20 PM	40
SW 155 St.	Southbound	4:40 PM	44
SW 173 St.	Southbound	4:55 PM	43
SW 195 St.	Southbound	5:15 PM	45
Average Mean PM Speed			***43***

4.2.3.2 AFTER-BUSWAY OPERATION

After the operation of the busway began, several problems arose. First, motorists crossing the busway experienced a tremendous delay. A number of accidents also occurred, which involved transit vehicles and other vehicles trying to cross the busway. For these reasons, the after-operation data collection was found to be necessary to see the impact of the busway operation on general traffic.

According to the recommendations of the Florida Department of Transportation (FDOT) District VI, 10 intersections were chosen for the after operation study. These intersections are those within 50 to 80 feet separation distance from the edge of the pavement of US 1 with the exception of SW 132 St. and SW 112 Ave. All ten intersections listed in **Table 4.9** were selected for turning movement counts (TMC), intersection delay study, intersection saturation flow, and automatic traffic counts (machine counts). The lanes configuration for the east and west bound crossing the busway and US 1 are shown in **Table 4.9.**

Table 4.9 - List of Selected Intersections for After-operation Study And Number of Lanes in Each Group

Intersection	East-Bound Configuration						West-Bound Configuration					
	L	L/T	T	R/T	R	Tot. No. of Lanes	L	L/T	T	R/T	R	Tot. No. of Lanes
SW 98 Street			1			1			LTR			1
SW 104 Street	1	1		1		3	1		1		1	3
SW 112 Street	1		LTR		1	2	1		1		1	3
SW 124 Street	1			1		2	1			1		2
SW 128 Street	1			1		2	1			1		2
SW 136 Street	2		2		1	5	2		1	1		4
SW 144 Street	1			1		2	1			1		2
SW 152 Street	1	1	1		1	4	1	1			1	3
SW 160 Street	1	1			1	3			LTR			1
SW 200 Street	1				1	2	2		1	1		2

Before the operation of the South Dade Busway there were only three transit bus routes (Route 1, Route 52, and Route 65) operating on US 1. After the busway operation, Route 52 was the only one moved to the exclusive busway right-of-way in addition to other new routes. The relocation of Route 52 from US 1 to the busway did not have significant impact on the congestion level of US

1 as it used to operate with a headway of 30 minutes and 60 minutes during the peak and off-peak periods, respectively. For this reason, the spot speed study for after-operation was excluded.

Automatic Machine Counts: Automatic machine counts were performed for the selected ten intersections. The purpose of this study was to determine the total 24-hour traffic volume at each approach, the peak hour, the peak hour volume, and the peak hour factor. Automatic counters were placed at each bound before approaching the intersection. Counts were taken for a period of 24 hours. The result of this study presented in **Table 4.10**, shows that the daily northbound volume ranged between 22,400 and 39,500 vehicles, while the daily southbound volume ranged between 25,000 and 42,300 vehicles. This study also shows that the AM peak hour varies from 6:45 a.m. to 7:45 a.m. for the northbound and the PM peak hour varies from 4:45 p.m. to 5:30 p.m.

Turning Movement Counts: Turning movement counts were performed at the ten intersections from 7:00 a.m. to 9:00 a.m., from 11:00 a.m. to 1:00 p.m., and from 4:00 p.m. to 6:00 p.m. A summary of the turning movement counts showing all the movements at each intersection in terms of the number of vehicles is shown in **Table 4.11**. **Table 4.12** presents the same data in percentile. Turning movement counts at each intersection were performed manually by two persons.

Intersection Delay Study: The intersection delay study for the after operation of the busway was performed for all ten intersections from 7:00 a.m. to 9:00 a.m. and from 4:00 p.m. to 6:00 p.m. Vehicles stopped at the studied intersections were counted every 13 seconds. The average delay per stopped vehicle was then calculated, as well as the average delay per approached vehicle and the percentage of vehicles stopped at each bound. A summary of the intersection delay study performed for all of the ten intersections is presented in **Table 4.13**. The average percentage of vehicles stopped for the eastbound AM and PM peaks are 90.44 and 90.24, respectively, and for the westbound are 78.55 and 89.19. This shows that the eastbound is affected more by the busway operation. The cause of this is that eastbound vehicles cannot make right turns to US 1 due to the operation of the busway. Eastbound right turn vehicles have to wait for green light, while before opening the busway vehicles had to wait for green time of wait for a suitable gap to accomplish this movement.

Saturation Flow Rate: The saturation flow rate is the equivalent hourly rate at which vehicles can traverse an intersection approach under prevailing conditions, assuming that the green signal is available at all times and no lost time is experienced, in vehicles per hour of green time or vehicles per hour or green time per lane. The saturation flow rate involves the observation of vehicles' headway as they enter into the intersection. The result of the saturation flow rate study is presented in **Table 4.14**.

Table 4.10 - Summary of the Automatic Counts at Selected Intersections Along Us 1 After the Busway Opening

INTERSECTION	PEAK PERIOD	NORTHBOUND				SOUTHBOUND				EASTBOUND				WESTBOUND			
		PH	PHV	PHF	24 T	PH	PHV	PHF	24 T	PH	PHV	PHF	24 T	PH	PHV	PHF	24 T
SW 98 St.	AM	6:45	2,601	0.93	31,934	11:30	1,878	0.92	29,456	8:15	475	0.91	5,083	7:45	223	0.71	2,496
	PM	7:00	2,133	0.86		5:15	2,831	0.94		4:45	398	0.90		12:00	228	0.91	
SW 104 St.	AM	6:45	3,270	0.94	39,169	11:30	2,629	0.96	42,258	7:45	759	0.94	9,309	7:45	657	0.97	7,704
	PM	1:30	2,467	0.97		5:00	3,792	0.97		2:30	660	0.94		3:15	597	0.94	
SW 112 St.	AM	6:30	3,144	0.95	38,595	11:30	2,306	0.86	38,715	7:00	542	0.92	6,604	11:15	665	0.93	8,998
	PM	2:00	2,418	0.96		5:30	3,390	0.97		12:00	444	0.93		14:15	748	0.95	
SW 124 St.	AM	6:45	3,172	0.94	38,662	11:30	2,111	0.94	33,771	8:00	470	0.86	5,668	8:15	329	0.88	5,024
	PM	2:30	2,509	0.94		5:00	2,908	0.95		5:00	435	0.91		2:00	425	0.97	
SW 128 St.	AM	6:30	3,150	0.97	36,517	11:30	1,995	0.86	32,605	8:00	345	0.98	4,101	8:00	380	0.83	4,970
	PM	1:45	2,298	0.96		5:30	2,823	0.94		4:15	386	0.86		2:00	393	0.96	
SW 136 St.	AM	6:45	3,159	0.98	37,693	11:30	1,992	0.85	32,417	11:30	740	0.83	11,860	11:30	776	0.91	10,570
	PM	1:00	2,463	0.95		5:30	3,013	0.97		5:00	924	0.94		2:00	928	0.95	
SW 144 St.	AM	6:30	3,179	0.97	38,708	11:30	1,897	0.82	33,780	7:45	464	0.94	5,862	11:30	372	0.78	5,334
	PM	1:30	2,468	0.97		5:00	2,974	0.94		3:00	419	0.95		4:45	443	0.94	
SW 152 St.	AM	7:45	3,235	0.98	39,439	11:30	2,051	0.98	34,099	8:00	1,140	0.91	15,131	11:30	801	0.91	11,729
	PM	7:45	2,408	0.96		5:00	3,038	0.97		7:15	1,011	0.92		4:15	947	0.93	
SW 160 St.	AM	7:30	2,247	0.94	28,719	11:15	1,784	0.95	28,585	6:15	518	0.93	6,685	11:30	160	0.87	2,346
	PM	1:15	1,949	0.96		4:45	2,490	0.97		3:45	484	0.88		4:45	214	0.84	
SW 200 St.	AM	7:30	1,533	0.95	22,480	11:30	1,512	0.90	25,062	7:00	712	0.85	9,085	7:00	896	0.94	14,029
	PM	3:15	1,614	0.99		5:00	2,062	0.94		5:00	605	0.96		15:45	970	0.97	

Table 4.11 - Summary of the Turning Movement Counts for Selected Intersections Along US 1 After the Opening of the Busway (number of vehicles)

INTERSECTION	PEAK HOUR	NORTHBOUND			SOUTHBOUND			EASTBOUND			WESTBOUND			PEAK HOUR VOLUME
		LF	TH	RT	LF	TH	RT	LF	TH	RT	LF	TH	RT	
SW 98 St.	8:00	200	2,246	20	25	949	89	141	114	92	8	118	66	4,068
	12:00	138	1,489	35	89	1,744	217	86	57	167	31	63	64	4,180
	5:00	113	1,313	22	108	2,553	317	85	127	147	28	132	54	4,999
SW 104 St.	7:30	63	2,702	23	199	1,531	87	468	301	50	29	101	315	5,869
	12:00	184	1,788	27	318	2,179	182	246	149	130	85	145	189	5,622
	4:00	204	1,658	17	284	3,182	366	215	141	150	65	141	166	6,589
SW 112 St.	7:15	76	3,292	56	67	1,355	58	181	230	40	35	147	42	5,579
	12:00	180	2,142	48	137	2,222	62	118	145	116	92	147	118	5,527
	5:00	199	2,196	33	111	2,847	88	83	130	78	78	222	70	6,135
SW 124 St.	7:15	103	3,015	56	43	1,258	44	165	152	33	81	125	75	5,150
	11:45	76	2,147	125	79	2,071	67	69	81	48	92	118	63	5,036
	4:00	157	1,838	118	85	2,689	122	84	121	62	105	129	84	5,594
SW 128 St.	7:15	61	2,973	75	29	1,156	117	136	131	41	34	88	58	4,899
	12:00	99	2,208	59	81	2,002	124	148	54	68	69	78	71	5,061
	4:30	61	1,994	58	68	2,751	148	158	124	88	68	110	44	5,672

Table 4.11 (Cont.) - **Summary of the Turning Movement Counts for Selected Intersections Along US 1 After the Opening of the Busway** (number of vehicles)

INTERSECTION	PEAK HOUR	NORTHBOUND			SOUTHBOUND			EASTBOUND			WESTBOUND			PEAK HOUR VOLUME
		LF	TH	RT	LF	TH	RT	LF	TH	RT	LF	TH	RT	
SW 136 St.	7:45	200	3,010	95	58	1,256	119	249	252	132	88	140	50	5,649
	12:00	268	1,597	78	167	1,779	325	318	219	236	232	226	105	5,550
	4:45	317	1,703	80	138	2,686	345	283	304	228	190	344	58	6,676
SW 144 St.	7:45	81	2,980	124	86	1,323	41	131	159	150	110	114	65	5,364
	12:00	134	1,899	142	101	1,965	61	58	55	155	134	92	121	4,917
	4:45	175	1,905	166	108	2,942	93	73	112	180	188	139	66	6,147
SW 152 St.	7:45	221	2,592	145	95	1,101	197	527	340	176	104	260	44	5,792
	11:45	248	1,627	101	149	1,536	271	368	183	241	172	171	95	5,162
	4:15	191	1,399	129	195	2,431	477	388	295	194	152	233	53	6,137
SW 160 St.	7:30	110	2,112	28	77	776	60	413	60	124	12	48	47	3,867
	11:45	211	1,673	23	57	1,561	241	1,778	26	219	38	45	21	4,293
	4:30	212	1,571	23	152	2,337	483	299	82	212	29	54	32	5,486
SW 200 St.	7:45	96	1,561	43	118	816	132	332	205	51	225	264	246	4,089
	12:00	81	1,365	66	229	1,161	192	197	197	69	206	177	206	4,146
	4:00	122	1,440	65	308	1,473	244	202	201	95	321	26	209	4,946

Table 4.12 - Summary of the Turning Movement Counts for Selected Intersections Along US 1 After the Opening of the Busway (percentage)

INTERSECTION	PEAK HOUR	NORTHBOUND			SOUTHBOUND			EASTBOUND			WESTBOUND			PEAK HOUR VOLUME
		LF	TH	RT	LF	TH	RT	LF	TH	RT	LF	TH	RT	
SW 98 St.	8:00	8%	91%	1%	2%	89%	8%	41%	33%	27%	4%	61%	34%	4,068
	12:00	8%	90%	2%	4%	85%	11%	28%	18%	54%	20%	40%	41%	4,180
	5:00	8%	91%	2%	4%	86%	11%	24%	35%	41%	13%	62%	25%	4,999
SW 104 St.	7:30	2%	97%	1%	11%	84%	5%	57%	37%	6%	7%	23%	71%	5,869
	12:00	9%	89%	1%	12%	81%	7%	47%	28%	25%	20%	35%	45%	5,622
	4:00	11%	88%	1%	7%	83%	10%	42%	28%	30%	17%	38%	45%	6,589
SW 112 St.	7:15	2%	96%	2%	5%	92%	4%	40%	51%	9%	16%	66%	19%	5,579
	12:00	8%	90%	2%	6%	92%	3%	31%	38%	31%	26%	41%	33%	5,527
	5:00	8%	90%	1%	4%	93%	3%	29%	45%	27%	21%	60%	19%	6,135
SW 124 St.	7:15	3%	35%	2%	3%	94%	3%	47%	43%	9%	29%	44%	27%	5,150
	11:45	3%	91%	5%	4%	93%	3%	35%	41%	24%	34%	43%	23%	5,036
	4:00	7%	87%	6%	3%	93%	4%	31%	45%	23%	33%	41%	26%	5,594
SW 128 St.	7:15	2%	96%	2%	2%	89%	9%	44%	43%	13%	19%	49%	32%	4,899
	12:00	4%	93%	2%	4%	91%	6%	55%	20%	25%	32%	36%	33%	5,061
	4:30	3%	94%	3%	2%	93%	5%	43%	34%	24%	31%	50%	20%	5,672

Table 4.12 (Cont.) - **Summary of the Turning Movement Counts for Selected Intersections Along US 1 After the Opening of the Busway** (percentage)

INTERSECTION	PEAK HOUR	NORTHBOUND			SOUTHBOUND			EASTBOUND			WESTBOUND			PEAK HOUR VOLUME
		LF	TH	RT	LF	TH	RT	LF	TH	RT	LF	TH	RT	
SW 136 St.	7:45	6%	91%	3%	4%	88%	8%	39%	40%	21%	32%	50%	18%	5,649
	12:00	14%	82%	4%	7%	78%	14%	41%	28%	31%	41%	40%	19%	5,550
	4:45	15%	81%	4%	4%	85%	11%	35%	37%	28%	32%	58%	10%	6,676
SW 144 St.	7:45	3%	94%	4%	6%	91%	3%	30%	36%	34%	38%	39%	22%	5,364
	12:00	6%	87%	7%	5%	92%	3%	22%	21%	58%	39%	27%	35%	4,917
	4:45	8%	85%	7%	3%	34%	3%	20%	31%	49%	48%	35%	17%	6,147
SW 152 St.	7:45	7%	88%	5%	7%	79%	14%	51%	33%	17%	25%	64%	11%	5,792
	11:45	13%	82%	5%	8%	79%	14%	46%	23%	30%	39%	39%	22%	5,162
	4:15	11%	81%	8%	6%	78%	15%	44%	34%	22%	35%	53%	12%	6,137
SW 160 St.	7:30	5%	94%	1%	8%	85%	7%	69%	10%	21%	11%	45%	44%	3,867
	11:45	11%	88%	1%	3%	84%	13%	42%	6%	52%	37%	43%	20%	4,293
	4:30	12%	87%	1%	5%	79%	16%	50%	14%	36%	25%	47%	28%	5,486
SW 200 St.	7:45	6%	92%	3%	11%	77%	12%	56%	35%	9%	31%	36%	33%	4,089
	12:00	5%	90%	4%	14%	73%	12%	43%	43%	15%	35%	30%	35%	4,146
	4:00	7%	89%	4%	15%	73%	12%	41%	40%	19%	40%	33%	26%	4,946

Table 4.13 - Summary of Delay Study at US 1 and Major Busway Intersections After the Busway Opening

Intersection	Peak	Direction	Movements		Total Delay		Average Delay/Stopped Vehicle (Sec.)	Average Delay/Approach Vehicle (Sec.)	Percentage of Veh. Stopped
			EB	WB	Veh. Sec	Veh. Hr			
SW 98 St.	AM	Eastbound			4,459	1.24	76	62	81.9
		Westbound			1,199	0.33	86	61	68.0
	PM	Eastbound			3,254	0.90	68	46	61.2
		Westbound			1,456	0.40	73	56	80.6
SW 104 St	AM	Eastbound			14,251	3.96	93	88	94.2
		Westbound			14,791	4.11	87	84	97.3
	PM	Eastbound			9,981	2.77	75	69	91.7
		Westbound			10,748	2.99	93	90	97.3
SW 112 St.	AM	Eastbound			14,645	4.07	122	117	95.1
		Westbound			4,986	1.38	83	63	74.7
	PM	Eastbound			13,601	3.78	152	144	93.8
		Westbound			1,333	0.37	123	105	85.2
SW 124 St.	AM	Eastbound			8,440	2.34	84	79	90.0
		Westbound			3,871	1.08	73	66	85.6
	PM	Eastbound			5,109	1.42	92	80	87.0
		Westbound			11,538	3.20	133	124	90.7
SW 128 St.	AM	Eastbound			5,684	1.58	98	91	89.4
		Westbound			2,321	0.64	76	63	76.0
	PM	Eastbound			5,902	1.64	92	83	86.7
		Westbound			4,722	1.31	96	85	85.5

Table 4.13 (Cont.) - **Summary of Delay Study at US 1 and Major Busway Intersections After the Busway Opening**

Intersection	Peak	Direction	Movements		Total Delay		Average Delay/Stopped Vehicle (Sec.)	Average Delay/Approach Vehicle (Sec.)	Intersection Delay (% of Veh. Stopped)
			EB	WB	veh. Sec	Veh. Hr			
SW 136 St.	AM	Eastbound			11,450	3.18	77	71	89.1
		Westbound			3,214	0.89	69	64	88.5
	PM	Eastbound			20,738	5.76	89	88	97.8
		Westbound			23,254	6.46	101	101	100.0
SW 144 St.	AM	Eastbound			8,063	2.24	77	71	91.7
		Westbound			4,066	1.13	81	75	92.1
	PM	Eastbound			9,305	2.58	276	276	99.8
		Westbound			12,214	3.39	107	105	98.0
SW 152 St.	AM	Eastbound			12,337	3.43	107	101	93.6
		Westbound			7,950	2.21	101	92	91.0
	PM	Eastbound			13,341	3.71	133	126	95.1
		Westbound			8,731	2.43	102	88	86.4
SW 160 St.	AM	Eastbound			11,200	3.11	89	87	97.1
		Westbound			1,596	0.44	75	69	90.8
	PM	Eastbound			8,762	2.43	97	92	93.8
		Westbound			3,312	0.92	109	104	93.1
SW 200 St.	AM	Eastbound			12,756	3.54	77	67	85.8
		Westbound			12,454	3.46	82	82	98.5
	PM	Eastbound			10,469	2.91	85	81	95.5
		Westbound			18,805	5.22	107	80	75.1

Table 4.14 - Summary of Traffic Study at US 1 and Major Busway Intersections After the Opening of the Busway

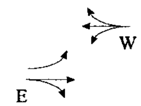
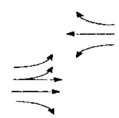
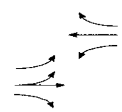
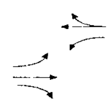
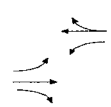
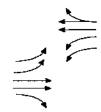
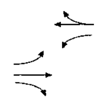
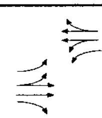
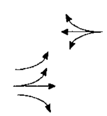
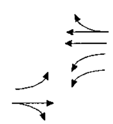
Intersection	Peak	Direction	Movements EB	Movements WB	Peak Hour Volume	Saturation Flow (per lane)	Intersection Delay (% of Veh. Stopped)
SW 98 St.	AM	Eastbound			347	1,822	81.9
		Westbound			192	1,377	68.0
	PM	Eastbound			359	1,730	61.2
		Westbound			214	947	80.6
SW 104 St	AM	Eastbound			819	1,788	94.2
		Westbound			445	> 2,200	97.3
	PM	Eastbound			506	1,574	91.7
		Westbound			372	1,542	97.3
SW 112 St.	AM	Eastbound			451	1,658	95.1
		Westbound			224	1,651	74.7
	PM	Eastbound			291	1,690	93.8
		Westbound			370	1,722	85.2
SW 124 St.	AM	Eastbound			350	1,469	90.0
		Westbound			281	1,505	85.6
	PM	Eastbound			267	1,124	87.0
		Westbound			318	1,863	90.7
SW 128 St.	AM	Eastbound			308	1,264	89.4
		Westbound			370	1,516	76.0
	PM	Eastbound			180	1,558	86.7
		Westbound			222	1,412	85.5

Table 4.14 (Cont.) - **Summary of Traffic Study at US 1 and Major Busway Intersections** (Cont.)
After the Opening of the Busway

Intersection	Peak	Direction	Movements (EB / WB)	Peak Hour Volume	Saturation Flow (per lane)	Intersection Delay (% of Veh. Stopped)
SW 136 St.	AM	Eastbound		633	1,883	89.1
		Westbound		278	1,224	88.5
	PM	Eastbound		815	2,105	97.8
		Westbound		592	1,700	100.0
SW 144 St.	AM	Eastbound		440	1,361	91.7
		Westbound		289	1,115	92.1
	PM	Eastbound		365	1,335	99.8
		Westbound		393	1,536	98.0
SW 152 St.	AM	Eastbound		1,043	1,376	93.6
		Westbound		408	1,866	91.0
	PM	Eastbound		877	1,643	95.1
		Westbound		438	1,614	86.4
SW 160 St.	AM	Eastbound		597	1,707	97.1
		Westbound		107	> 2,200	90.8
	PM	Eastbound		593	1,774	93.8
		Westbound		115	> 2,200	93.1
SW 200 St.	AM	Eastbound		588	1,694	85.8
		Westbound		735	1,620	98.5
	PM	Eastbound		498	1,552	95.5
		Westbound		796	1,608	75.1

4.2.3.3 TRAFFIC DATA ANALYSIS

By comparing the turning movement counts before and after the operation of the busway (see **Tables 4.15 and 4.16**), it is concluded that most of the intersections experienced fewer people driving through these intersections. **Tables 4.15** and **4.16** also revealed that for three-fifths of the intersections the total intersection volume has decreased ranging from 5% to 13%. The decrease in traffic volume may be due to the reduction of the green time for US 1 traffic, as a result of the additional signal phase (and green time) for the at-grade busway operation. For intersections with increased number of vehicles, the percentage increase was found to be 2%. This increase is not significant and might be due to different days of the week when the counts were performed. These tables also show that there is a forward shift in the peak hour due to the operation of the busway. This shift in the AM peak hour ranges from 15 to 30 minutes, while the PM peak hour ranges from 15 minutes to 1 hour. Presented in **Tables 4.17** and **4.18** are the summarized turning movement changes during the AM and PM peak periods for selected intersections along US 1 due to the busway operation.

The data presented in **Table 4.14** show that the peak hour flow does not exceed the saturation flow per lane. At the mean time the intersection delay study shows that the average percentage of vehicles stopped at the intersections is 89.1%. This delay is due to the reallocating of the green time to the busway, thus reducing the green time for traffic crossing US 1.

Because of a series of accidents that occurred after the operation of the busway, the FDOT deactivated the vehicle motion detectors on the busway. This means that all transit vehicles have to stop at each intersection and wait for the green time before crossing the intersection. In this case, the eastbound right turns can be permitted. The percentages of the eastbound right turns shown in table 9 range from 6% to 54%. Allowing this movement, the intersection delays may be significantly reduced.

Table 4.15 - Changes in AM Peak Turning Movement Counts for Selected Intersections along US 1 Due to the Busway Opening

INTERSECTION	PEAK HOUR		NORTHBOUND			SOUTHBOUND			EASTBOUND			WESTBOUND			TOTAL VOLUME
	Oper.	Time	LF	TH	RT	LF	TH	RT	LF	TH	RT	LF	TH	RT	
SW 104 St.	Before	7:45	106	2,765	12	226	1,829	101	290	154	32	38	176	265	5,994
	After	7:30	63	2,702	23	199	1,531	87	344	236	51	29	101	315	5,681
	Change	*(00:15)*	*(41)%*	*(2)%*	*92%*	*(12)%*	*(16)%*	*(14)%*	*19%*	*53%*	*59%*	*(24)%*	*(43)%*	*19%*	*(5)%*
SW 136 St.	Before	8:00	179	2,716	81	57	1,251	331	207	207	165	127	178	54	5,553
	After	7:45	200	3,010	95	58	1,256	119	249	252	132	88	140	50	5,649
	Change	*(00:15)*	*12%*	*11%*	*17%*	*2%*	*0%*	*(64)%*	*20%*	*22%*	*(20)%*	*(31)%*	*(21)%*	*(7)%*	*2%*
SW 152 St.	Before	8:00	293	2,385	96	144	728	448	591	266	183	154	306	62	5,656
	After	7:45	211	2,592	145	95	1,101	197	527	340	176	104	260	44	5,792
	Change	*(00:15)*	*(28)%*	*9%*	*51%*	*(34)%*	*51%*	*(56)%*	*(11)%*	*28%*	*(4)%*	*(32)%*	*(15)%*	*(29)%*	*2%*
SW 160 St.	Before	8:00	89	2,222	16	62	1,048	122	322	66	115	13	59	32	4,166
	After	7:30	110	2,112	28	77	776	60	413	60	124	12	48	47	3,867
	Change	*(00:30)*	*24%*	*(5)%*	*75%*	*24%*	*(26)%*	*(51)%*	*28%*	*(9)%*	*8%*	*(8)%*	*(19)%*	*47%*	*(7)%*
SW 200 St.	Before	7:45	96	2,043	26	117	853	152	422	223	62	229	296	204	4,723
	After	7:45	96	1,561	43	118	816	132	332	205	51	225	264	246	4,089
	Change	*(00:00)*	*0%*	*(24)%*	*65%*	*1%*	*(4)%*	*(13)%*	*(21)%*	*(8)%*	*(18)%*	*(2)%*	*(11)%*	*21%*	*(13)%*

Table 4.16 - Changes in PM Peak Traffic Movement Counts for Selected Intersections along US 1 Due to the Busway Opening

INTERSECTION	PEAK HOUR		NORTHBOUND			SOUTHBOUND			EASTBOUND			WESTBOUND			TOTAL VOLUME
	Oper.	Time	LF	TH	RT	LF	TH	RT	LF	TH	RT	LF	TH	RT	
SW 104 St.	Before	4:45	171	2,122	16	345	3,147	287	186	201	111	68	159	89	6,902
	After	4:00	204	1,658	17	284	3,182	366	215	141	150	65	141	166	6,589
	Change	*(00:45)*	*19%*	*(22)%*	*6%*	*(18)%*	*1%*	*28%*	*16%*	*(30)%*	*35%*	*(4)%*	*(11)%*	*87%*	*(5)%*
SW 136 St.	Before	4:45	220	1,520	107	154	2,958	319	265	241	147	256	302	68	6,557
	After	4:45	317	1,703	80	138	2,686	345	283	304	228	190	344	58	6,676
	Change	*(00:00)*	*44%*	*12%*	*(25)%*	*(10)%*	*(9)%*	*8%*	*7%*	*26%*	*55%*	*(26)%*	*14%*	*(15)%*	*2%*
SW 152 St.	Before	4:30	238	1,591	126	181	2,671	363	300	282	303	272	314	56	6,697
	After	4:15	191	1,399	129	195	2,431	477	388	295	194	152	233	53	6,137
	Change	*(00:15)*	*(20)%*	*(12)%*	*2%*	*8%*	*(9)%*	*31%*	*29%*	*5%*	*(36)%*	*(44)%*	*(26)%*	*(5)%*	*(8)%*
SW 160 St.	Before	4:45	171	1,650	25	79	2,497	305	243	103	152	26	65	32	5,348
	After	4:30	212	1,571	23	152	2,337	483	299	82	212	29	54	32	5,486
	Change	*(00:15)*	*24%*	*(5)%*	*(8)%*	*92%*	*(6)%*	*58%*	*23%*	*(20)%*	*39%*	*12%*	*(17)%*	*0%*	*3%*
SW 200 St.	Before	5:00	144	1,434	76	287	1,596	349	274	247	97	329	342	365	5,540
	After	4:00	122	1,440	65	308	1,473	244	202	201	95	321	266	209	4,946
	Change	*(01:00)*	*(15)%*	*0%*	*(14)%*	*7%*	*(8)%*	*(30)%*	*(26)%*	*(19)%*	*(2)%*	*(2)%*	*(22)%*	*(43)%*	*(11)%*

Table 4.17 - Summary of Changes in AM Peak Turning Movement Counts for Selected Intersections Along US 1 Due to the Busway Opening

INTERSECTION	PEAK HOUR		NORTHBOUND	SOUTHBOUND	EASTBOUND	WESTBOUND	INTERSECTION VOLUME
	Oper.	Tme					
SW 104 St.	Before	7:45	2,883	2,156	476	479	5,994
	After	7:30	2,788	1,817	631	445	5,681
	Change	*(00:15)*	(3)%	(19)%	25%	(8)%	(6)%
SW 136 St.	Before	7:45	2,976	1,639	579	359	5,553
	After	7:30	3,305	1,433	633	278	5,649
	Change	*(00:15)*	10%	(14)%	9%	(29)%	2%
SW 152 St.	Before	7:45	2,774	1,320	1,040	522	5,656
	After	7:30	2,948	1,393	1,043	408	5,792
	Change	*(00:15)*	6%	5%	0%	(28)%	2%
SW 160 St.	Before	7:45	2,327	1,232	503	104	4,166
	After	7:30	2,250	913	597	107	3,867
	Change	*(00:15)*	(3)%	(35)%	16%	3%	(8)%
SW 200 St.	Before	7:45	2,165	1,122	707	729	4,723
	After	7;30	1,700	1,066	588	735	4,089
	Change	*(00:15)*	(27)%	(5)%	(20)%	1%	(16)%

Table 4.18 - Summary of Changes in PM Peak Turning Movement Counts for Selected Intersections along US 1 Due to the Busway Opening

INTERSECTION	PEAK HOUR		NORTHBOUND	SOUTHBOUND	EASTBOUND	WESTBOUND	INTERSECTION VOLUME
	Oper.	Time					
SW 104 St.	Before	4:45	2,309	3,779	498	316	6,902
	After	4:00	1,879	3,832	506	372	6,598
	Change	*(00:45)*	(23)%	1%	2%	15%	(5)%
SW 136 St.	Before	4:45	1,847	3,431	653	626	6,557
	After	4:00	2,100	3,169	815	592	6,676
	Change	*(00:45)*	12%	(8)%	20%	(6)%	2%
SW 152 St.	Before	4:45	1,955	3,215	885	642	6,697
	After	4:00	1,719	3,103	877	438	6,137
	Change	*(00:45)*	(14)%	(4)%	(1)%	(47)%	(9)%
SW 160 St.	Before	4:45	1,846	2,881	498	123	5,348
	After	4:00	1,806	2,972	593	115	5,486
	Change	*(00:45)*	(2)%	3%	16%	(7)%	3%
SW 200 St.	Before	4:45	1,654	2,232	618	1,036	5,540
	After	4:00	1,627	2,025	498	796	4,946
	Change	*(00:45)*	(2)%	(10)%	(24)%	(30)%	(12)%

4.2.4 Accident Data Collection and Analysis

Between February and June of 1997, 14 accidents have occurred involving transit vehicles with private or commercial vehicles and resulting in 54 injuries. All accidents occurred where the busway and cross street intersections are far away from US 1. The separation distance ranges between 250 and 400 feet. Five of the 14 transit vehicles (three buses and nine paratransit vehicles) involved in these accidents were heading north and nine were heading south. All vehicles that collided with transit vehicles were heading east as shown in **Figure 4.15**. Accident statistics about South Dade Busway is shown in **Table 4.19**. A possible cause of these accidents may be

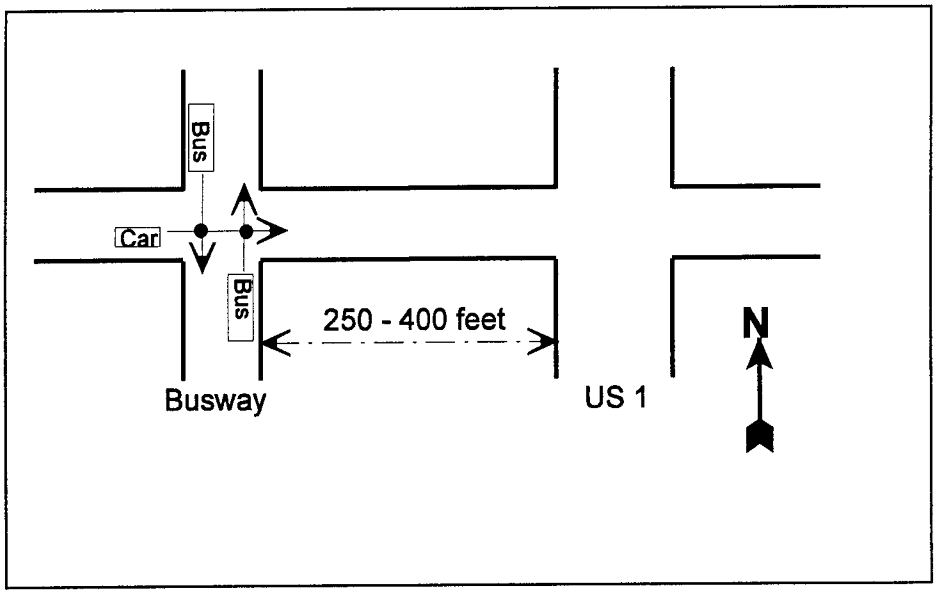


Figure 4.15 - Typical Layout of Intersections with High Accident Frequency

motorists' confusion due to multiple signals within a short distance at some intersections. Each of these intersections has at least two traffic signals, one for crossing the busway and the other for crossing US 1. An exception is SW 168 St., where there are three consecutive signals within a distance of 550 feet, as shown in **Figure 4.16**. According to *June 21, 1997 issue of Miami Herald*, "*A driver heading east may encounter a red light at the busway, but see a green light at US 1 and drive through the busway.*" Several visits were made to the accident site and it was found that there is a very small chance that this could happen due to several reasons. Firstly, usually the eastbound will have a green time all the time unless a bus is approaching the intersection. The headways between the buses are about three minutes during the peak hour and seven to ten minutes during the off-peak. Secondly, the green time allowed for crossing US 1 ranges between 17 and 25 seconds. This time is very short. Thus, the chance of a bus arriving to the intersection at this time is minimal. The possible cause of accidents may therefore be one of the following:

1. Motorists are not aware of the existence of the busway between SW 168 Street and Marlin Drive, so they pass through the intersection without paying attention to the new busway;

2. Some busway crossings have a red signal but no bus is approaching. As a result, motorists do not stop when they observe a red light at the busway crossing, especially at an intersection with poor visibility that prevent drivers from seeing clearly an approaching bus. The red light without a bus entering the intersection might be due to the conflict between the location of some stops and the advanced vehicle detectors. With the installation of the detectors, all stations should be located at the far-side of the intersection. Otherwise, when a bus passes over the detectors a green light is activated for the busway and red light for the cross street and instead of crossing the intersection the bus will stop at the station, located at the near-side of the intersection, to alight and board passengers; or

3. A speed of 40 mph is used to program the advanced vehicle detectors, so when a bus passes over the detectors traveling at 40 mph, the bus will have a green signal when reaching the intersection. As it was observed, bus drivers usually exceed the posted speed limit on the busway (40 mph) trying to catch up with the schedule, thus eastbound vehicles arriving to the busway intersection at the dilemma zone do not have enough time to clear the intersection to allow the buses to pass.

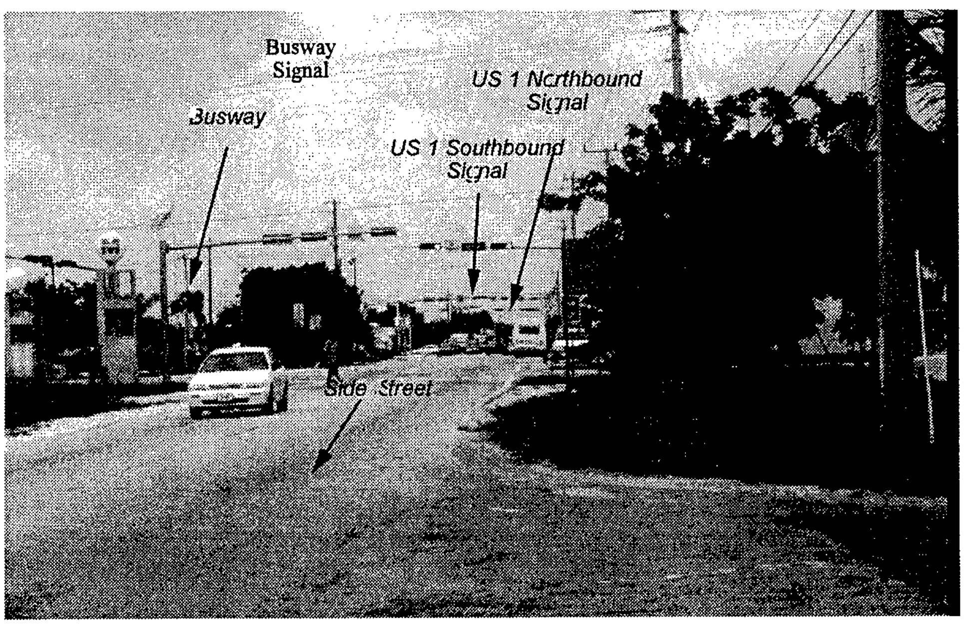


Figure 4.16 - Eastbound Traffic Signals at SW 168 Street

Table 4.19 - Summary of Accident Statistics for South Dade Busway

Location	Number of Accidents	Number & Type of Transit Vehicles	Number & Direction of Transit Vehicle	Number & Direction of Other Vehicle	Number of Injuries
SW 168 St.	3	3P	2N, 1S	3 East	17
SW 174 St.	1	1B	1S	East	0
SW 184 St.	3	3P	3S	3 East	8
SW 186 St.	3	1P, 2B	3S	3 East	4
Marlin Dr.	4	4P	3N, 1S	4 East	25
Total	**14**	**11P, 3B**	**5N, 9S**	**14 East**	**54**

where: P = Paratransit Bus (Mini-bus)
B = Metro Dade Bus (Full size bus)
N = Northbound
S = Southbound

As a result of these 14 accidents involving buses and private vehicles at the busway crossings, FDOT took the following actions:

1. Vehicle detectors between SW 168 Street and Marlin Drive are disconnected. This means that all buses have to stop at the intersection and wait for a green light. In other words, buses no longer have signal priority between SW 168 Street and Marlin Drive. Although this solution has efficiently reduced the number of accidents, it leads to an increase in the bus trip time.

2. Installation of yellow, diamond shaped signs to warn the motorists of traffic signals at the busway.

Any increase in the bus trip time may lead to a decrease in the ridership. Other possible solutions may be considered to improve the safety at the intersections. Some of the following proposed solutions are costly, but may be justified by the safety of the transit riders and motorists. Some of these solutions are shown in **Figure 4.17**.

1. All bus stops should be at the far side of the intersection. This will incur large expenses for relocating the bus shelters and reconfigure the busway for bus bays at new stop locations.

2. Install internally illuminated "BUS COMING" signs at all intersections to warn eastbound and westbound motorists about approaching buses. These signs will be activated when a bus passes over the vehicle detectors installed in the busway. These signs can also be

installed at US 1 southbound right turn lanes.

3. Improve visibility at busway crossings for both the motorists and buses, if possible.

4. Installation of optically programmed signals at all US 1 crossings to avoid the motorists' confusion where more than one signal occurs. The same signals are installed north of SW 168 Street.

5. Replace 8-inch red signal indicators with 12-inch indicators at the busway crossings.

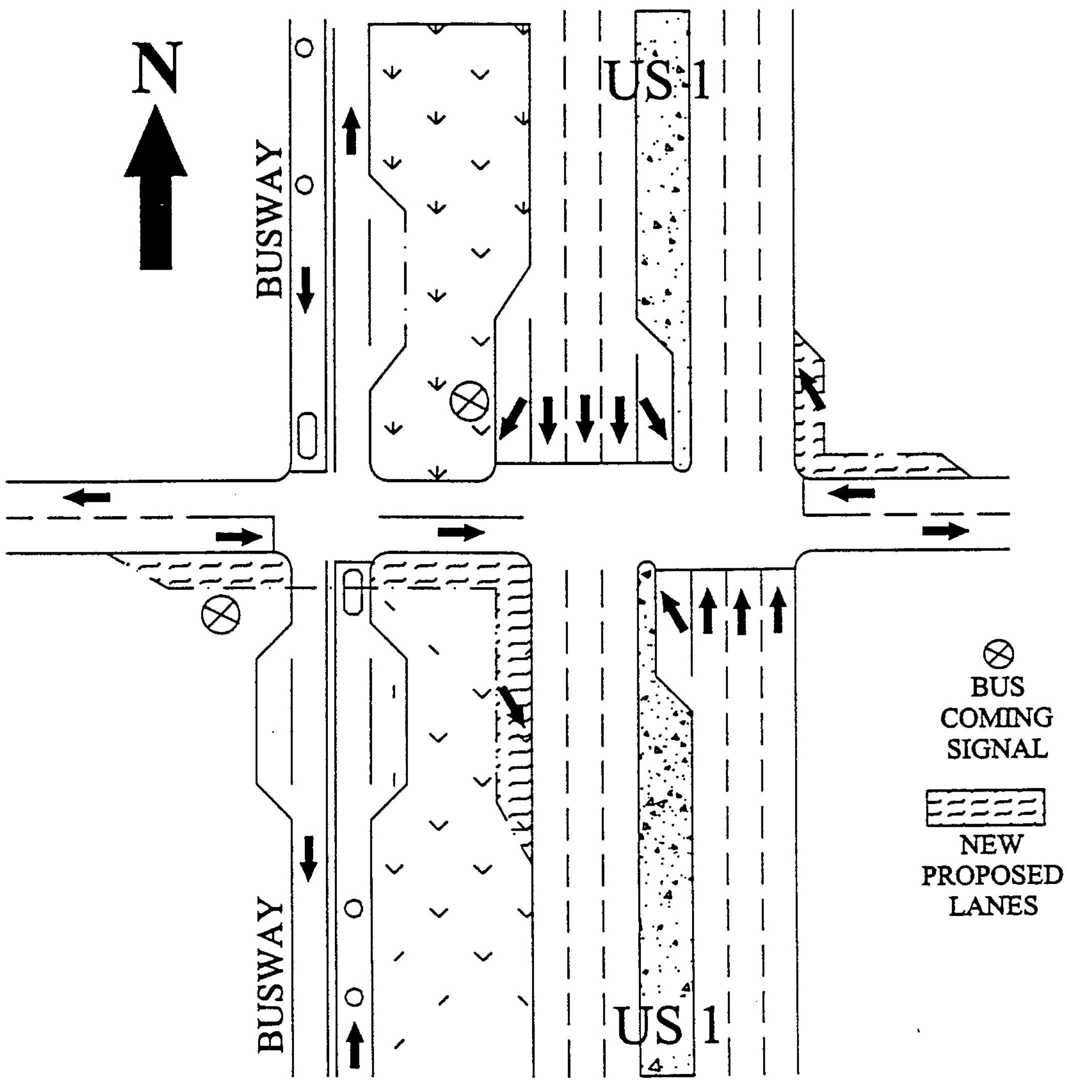


Figure 4.17 - Proposed Solutions for the Busway

5 SYSTEM CHARACTERISTICS OF AT-GRADE BUSWAYS

5.1 General Characteristics

The most important advantages of at-grade busways result from three basic features related to buses as a transit mode:

1. The ability to operate on most streets because buses, unlike rail transit modes, contain their own power supply system. This ability gives buses several advantages over other transit modes. Also, the ability and flexibility of placing bus routes on any street and their stops can be placed at any point make their implementation much easier than rail transit modes.

2. Low investment costs and quick implementation schedules make at-grade busways more attractive to potential and medium capacity applications.

5.2 Service Characteristics

The main service attribute for busways is the operating speed. Buses operating in exclusive rights-of-way can usually gain speeds of up to 50 mph (80 km/hr) depending on the distances between stations and at-grade intersections. Another speed advantage is that transit vehicles can skip any non-scheduled stops. Thus, it can bypass transit vehicles in station areas. In case of a transit vehicle breakdown, the ability of other transit vehicles to continue to operate on busway contributes to system reliability. While buses on exclusive busways are able to maintain high speeds, the existing busway systems have shown low accident rates.

Other main service advantages of the busways are flexibility and accessibility. At-grade busways can operate on integrated route extensions that allow for a wide range of service levels including one-seat origin-to-destination trips. Route may be easily modified in terms of route extensions and headways without significant capital or time investments.

A comparison of the passenger per route mile between busways and LRT is shown in **Table 5.1**. Ottawa transitway has a higher daily ridership than any LRT systems in the United States except for Boston. The two busway systems in Pittsburgh have higher passengers per route mile than most of the LRT systems in the United States. It is also concluded that the average passengers per route mile for busways were 7,448 while LRTs were 3,098. This signifies that busways accommodate a larger percentage of commuters daily.

Table 5.1 Passengers per Route Mile for Busways and LRT

CITY	YEAR FIRST OPENED	ROUTE MILES	DAILY PASSENGERS[a]	PASSENGER PER ROUTE MILE
EXCLUSIVE BUSWAYS				
OTTAWA	1983	12.5	200,000	16,600
PITTSBURGH	1977	10.3	46,500	4,515
MIAMI	1997	8.2	10,066	1,228
LIGHT RAIL				
BOSTON	1987	58.6	236,700	4,039
CALGARY	1981	16.8	136,700	8,137
PORTLAND	1986	15.4	31,000	2,013
SAN DIEGO	1981	20.4	56,400	2,765
PITTSBURGH	1981	22.5	25,800	1,147
SACRAMENTO	1987	18.3	27,000	1,475
SAN JOSE	1987	20.6	23,200	1,126
BUFFALO	1985	6.4	26,100	4,078

(a) 1997 Statistics

Sources: OC Transpo Memorandum to members of the commission, 01/06/93.

5.3 Cost Characteristics

The first cost analysis for rapid transit modes including busways performed by Meyer et al. in 1965, had examined express buses and freeway fliers as two forms of busways. The study showed that express buses have significantly lower costs per passenger trip than heavy rail systems, except for very short routes with very high volumes in high residential densities. On the other hand, the same study showed that freeway fliers had lower costs than heavy rail in all situations considered. The study also concluded that as passenger volumes increase, the extent of the at-grade busway cost advantage decreases. Thus, the break-even volume between busway and heavy rail was found to be 50,000 per hour direction. The low investment cost advantage of at-grade busways makes rapid introductions, changes, and extensions of bus routes and stops very easy. Unlike the rapid rail systems, busways do not require complex power distribution systems, control systems, vehicle-to-vehicle guideway interfaces, and vehicle specifications. Also, rapid rail systems must have maintenance facilities connected to the guideway. Such facilities are usually located near the CBD where the value of the land is relatively high. Moreover, not only busways are cost effective, but they are more accurate to estimate due to the similarities between busways and highways. Although busways require larger stations, special rights-of-way, and regulatory equipment, their costs are less than those of rail transit systems and can be implemented in a shorter amount of time. The average percentage of cost overrun for the construction of heavy rail systems is 158%, while the similar percentage for light rail systems is 127%. The construction cost of the South Dade Busway was overrun by only 21%, while in the mean time the actual construction cost for Ottawa Transitway was 1.37% lower than the forecasted. A cost comparison of modal systems is shown in **Table 5.2**. It should be noted that the capital cost and cost per mile of the at-grade busway and the transitway do not include the cost of vehicles. The cost information for the light rail presented in this table is the average of the 18 existing systems in the United Stated and Canada. This analysis reveals that the transitway has the largest average daily ridership and minimum headway, while the busway has the lowest capital cost per mile. The average operating cost for Ottawa transitway is 3.9 cents/seat-mile, yielding an average total cost of only nine cents/seat-mile.

Table 5.2 Cost Comparison of Modal Systems

CHARACTERISTICS	UNITS	SOUTH DADE AT-GRADE BUSWAY[A]	OTTAWA TRANSITWAY[B]	LIGHT RAIL[c]
Capital Cost (includes R. O. W. cost)	million	56.8*	420*	429
Length of System	miles	8.2	19.4	20.4
Capital Cost per mile	million/mile	6.9*	21.6*	19.4 - 148.0**
Max. Operational Speed	mph	40	55	51
O & M Cost - Vehicles	$/vehicle mile	N/A	N/A	11.5[(1994)]
Minimum Headway Operated	seconds	300-600	15-30	396
Veh. Capacity - Seats	seats/vehicle	53	53	63
Veh. Capacity - Persons	person/vehicle	85	85	183
Average Daily Ridership	person/hour	10,066	200,000	61,700

ROW = Right of Way [(a)] South Dade At-Grade Busway Statistics, [(b)] Ottawa Transit Statistics, [(c)] Average of 18 Existing LRT Systems in the US and Canada (1996)
*Capital cost and cost per mile for the At-Grade Busway and Transitway do not include vehicle cost
**Range of the capital cost per mile for some selected system in the United States and Canada

Sources: The Urban Transportation Monitor, August 30, 1996
OC Transpo Facts Sheet, 1996
MDTA - (Metro Dade Transit Authority), 1997

6 CONCLUSION

The capital and operating costs of at-grade busways are less than those of light rail and heavy rail transit systems. When comparing the costs and passenger volumes of the busway systems with those of light rail transit systems, it is clear that busways are an attractive alternative to rail in certain situations. At-grade busways may be implemented incrementally and thus are responsive to growing road congestion and new opportunities to influence changing land use patterns. This flexibility enables busways to maintain their position as an integral component of North American urban transportation. Buses have the flexibility to go anywhere where there is an adequately paved street or highway, with the freedom from traffic intervention enjoyed by other modes of rapid transit. Buses can also operate on most city streets mixed with general traffic serving residential neighborhoods, then join the exclusive busway facility providing a one seat connection, or in some cases no more than two transfers.

Service patterns may be tailored to requirements. For example, in the peak hours, service intensity may be increased in the peak direction and in the off-peak direction the bus may skip all stops to go back to the point of origin and make another peak direction trip. In light rail, however, almost all trains make all stops, resulting in slower service level. At-grade busways may be easily converted into medium capacity systems such as light rail transit systems. During the design phase, busways may be designed so that it may be converted into a light rail transit system to increase the overall line-haul capacity.

Based on the European experiences, busways may become an integral part of urban planning. With well-planned land uses and roadway design, busways may provide a high level of service to a large portion of the population with a low capital cost.

Conclusions that emerge from this study are as follows:

1. Important aspects of at-grade busway design and operations are safety, convenience, signal preemption for transit vehicles, and proper applications of traffic control devices. At intersections where the are more that one traffic signal, one for crossing the busway and another for the main corridor, traffic signal should be placed in such a way to minimize the conflict between the two signals. Also flashing light may be installed to warn drivers with an approaching bus. Several other safety aspects may be inherited from the operation of light rail systems.

2. The absence of guideway and overhead power supplies make busways unobtrusive, however, the noise and air pollution may be objectionable when large number of buses use the busway. The unobtrusiveness of busways may also result in less awareness of its existence. In some cases, such unawareness may be the cause of traffic accidents.

3. Busway operations may have negative impact on traffic on adjacent streets. Thus, traffic control signals should be carefully designed and tuned to minimize the impact on other streets. Traffic on several side streets crossing the South Dade Busway had experienced heavy delays due to the operation of the busway. This delay may be due to the conflict between the location of the bus stops and the advanced vehicle detectors or due to improper signal timing. Redesigning the geometrical configuration of an intersection may be a solution to some of the traffic problems occurred after the operation of the busway.

4. Availability of park-and-ride facilities is a strong incentive to the use of busway. In the case of the South Dade Busway, two bus stop locations with park-and-ride lots are also the high-volume stations.

5. Public awareness and public education are important. Automobile drivers should be informed of busway operation pattern, traffic control devices, and potential problems if traffic rules, signs, and signals are not obeyed. Positive press coverage, especially on significant increase of ridership and heavy use of the busway, will help promote the busway as an attractive travel mode and offset the possible impact on traffic on existing roads.

6. At-grade busways do not necessarily present a barrier to pedestrian movement unless the volume becomes high. In the case of the South Dade Busway, the parallel U.S. 1 is in fact a significant barrier to pedestrians.

7. Careful engineering study should be performed on traffic control and operation before busway operation. Simulation will benefit the signal design and identify potential accident sites and situations. This is extremely important to minimize the negative impact on an at-grade busway.

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